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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1959 SOUTHWESTERN MEETING

AT THE

UNIVERSITY OF TEXAS, AUSTIN, TEXAS

March 6–7

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March 6, 1959 Series II, Vol. 4, No. 2.

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1959 Southwestern Meeting, University of Texas at Austin, March 6–7, 1959

WITH the advent of 1959 we resume the sequence of our **Southwestern meetings,** interrupted in 1958 because of the setting of our convention of November, 1957, in a city on the borders of the Southwest. We return to **Austin and the University of Texas,** the city and the host of our Southwestern meeting of 1954. The scientific sessions will be held in the Physics Building and the Batts Auditorium of the University, the banquet in the Hotel Driskill. The Chairman of the Local Committee, to whom we are indebted for the welcome invitation as well as for the toil of arranging and managing the meeting, is Professor C. W. Horton.

Austin is an attractive city of stately buildings, more hilly than will be expected by those who know only eastern Texas. It is on the Missouri Pacific and the Frisco railroads from St. Louis to San Antonio; as of this writing, there is a through Pullman from New York over the Pennsylvania as far as St. Louis, then over the Missouri Pacific. People coming from east or west by the Southern Pacific and people coming from Mexico City should change at San Antonio, a city well worth a visit in itself. When we last met in Austin, it was at the end of the month of February, and on the first day of the meeting the temperature reached 93° and on the second 48°. This note is inserted for the benefit of those who will want to know what weight of clothing to take to the meeting.

The **Hotel Driskill** will place our members—those who write to it—in its own rooms so long as the supply of these holds out, and in rooms in other hotels of the same status after its own are all taken. Rates in the leading Austin hotels begin at $5 or $5.50 for singles, $7.50 or $8 for twin-bed rooms, and $14 or $15 for suites. From the leading hotels to the University it is a short and pleasant walk, but those who have succumbed to the motor era can go by taxi.

Registration will be in the Batts Auditorium. The registration fee will be one dollar. Tickets for the dinner will be sold at the registration desk, and there will be a blackboard nearby for official notices and for messages to members and guests of the Society. Messages will not be announced on this board if handed in by people who have not paid the registration fee.

Invited papers on the general programme will be given by W. P. Allis, E. H. Bommel, W. W. Buechner, A. von Engel, C. M. Fowler, R. G. Fowler, J. J. Griffin, H. P. Hanson, M. King Hubbert, D. S. Hughes, E. C. Kerr, B. B. Kinsey, J. S. Levinger, L. B. Loeb, L. Marton, G. C. Phillips, V. H. Regener, H. E. Rorschach Jr., C. F. Squire, W. Tobocman, M. S. Vallarta, and J. L. Yarnell. We have desisted from our earlier policy of giving primacy to geophysics, and the diversity of topics among these papers is wide indeed. Cryogenics, gaseous electronics including plasma physics, and nuclear physics are represented each by three or more among them, and geophysics is not forgotten.

Seventy contributed papers are distributed among seven sessions. Dominant is the topic here described as "reactions of transmutation." It is interesting to note that by comparison with Eastern meetings, papers in molecular and atomic spectroscopy are relatively abundant, papers in semiconductor physics very few. Incidentally there is a remarkably neat match between the number of sessions required for the papers and the number of halls available, but it had to be achieved in Procrustean fashion by lopping off some of the invited papers that had been strongly recommended.

The **banquet of the Society** will be held on Friday evening at seven in the Crystal Room of the Hotel Driskill. This is one of the occasions on which we unfortunately must give a guarantee on the day before the meeting begins. If we set it too low, some people will be frustrated by finding that there are no tickets left when they come to buy; but if we set it too high, the Society loses money. Some loss we are willing to risk for this, because we regard the banquet as an important feature of the meeting

and feel that everybody should attend it; but there has to be a limit. We entreat the members to fill out and mail the form to be found on the lower half of page 123. Those who pay by checks mailed with the form and received not later than Thursday morning, March 5, in Austin will find their tickets waiting for them: others are asked to buy as early as possible on Friday. The price will be $3.50. J. B. Morris will be an after-dinner speaker, and others will be announced on the blackboard.

A **cocktail hour,** which we owe to the generosity of Texas Nuclear Corporation and Texas Research Associates Corporation, will precede the banquet, beginning at 6 P.M. in the Maximilian Room of the Hotel Driskill. In this room, notice the splendidly framed mirrors which are reputed to have come from the palace of Maximilian and Carlota at Chapultepec.

For the ladies a **luncheon and style show** have been scheduled for twelve noon on Friday in the Colonial Room of the Hotel Driskill. The price is $1.75. They, or their menfolk for them, are specially asked to notify Professor Horton in advance: there is a place for this in the form on page 123.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society (the address below) not later than Friday, February 27. The titles of such as may be accepted will be written upon a blackboard near the registration desk, and opportunity will be given for the presentation of such papers (under the ten-minute rule) at the end of Session P or possibly elsewhere in the programme.

Errata pertaining to abstracts in this issue will be published in a later issue of the Bulletin if received not later than Monday, March 8, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "Instead of . . . read . . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1959 ANNUAL MEETING

(Personal names are those of invited speakers.)

Friday Morning

10:15 A. Von Engel, Loeb, R. G. Fowler. Batts Auditorium.

10:15 B. Solid-state physics; cryogenics. Physics 203.

10:15 C. Reactions of transmutation, I. Physics 201.

Friday Afternoon

2:00 E. Vallarta, Kinsey, Allis, C. M. Fowler. Batts Auditorium.

2:00 F. Marton, Hubbert, Hughes, Bommel. Physics 201.

2:00 G. Reactions of transmutation, II; Griffin. Physics 203.

Friday Evening

6:00 Cocktail party. Maximilian Room, Hotel Driskill.

7:00 Banquet. Crystal Room, Hotel Driskill.

Saturday Morning

9:30 J. Kerr, Yarnell, Rorschach, Squire. Batts Auditorium.

9:30 K. Buechner, Phillips, Levinger, Tobocman. Physics 201.

9:30 L. General nuclear physics; magnetic resonance. Physics 203.

Saturday Afternoon

1:30 N. Gaseous electronics; theoretical physics, general physics. Batts Auditorium.

1:30 P. Scattering of nucleons and nuclei. Physics 201.

1:30 Q. Hanson; x-ray and optical spectroscopy. Physics 203.

PROGRAMME

FRIDAY MORNING AT 10:15

Batts Auditorium

(W. P. ALLIS presiding)

Invited Papers in Gaseous Electronics

A1. Excitation of Atomic and Molecular Gases by Electrons. A. VON ENGEL, *University of Oklahoma.* (30 min.)

A2. The Role of Ionizing Potential Space Waves in Catastrophic Spark-Like Breakdown. L. B. LOEB, *University of California, Berkeley.* (30 min.)

A3. Recent Investigations of the Schottky Theory of the Positive Column. R. G. FOWLER, *University of Oklahoma.* (30 min.)

FRIDAY MORNING AT 10:15

Physics Building, 203

(C. F. SQUIRE presiding)

Solid-State Physics; Cryogenics

B1. Elastic Constants and Specific Heat of Calcium Fluoride.* M. H. NORWOOD AND D. R. HUFFMAN, *The Rice Institute.*—Measurements of specific heat at low temperatures and of elastic constants from 4°K to 300°K have been made for calcium fluoride single crystals. Initial results indicate that at 0°K $C_{11}=17.4$, $C_{12}=5.7$, and $C_{44}=3.56$ in units of 10^{11} dynes/cm². Preliminary measurements of specific heat indicate that θ_0, the Debye theta at 0°K has a value 506°K. θ_0 calculated from the elastic constants is 510°K. These values are significantly higher than those calculated from previous specific heat measurements.

* Supported in part by a grant from the National Science Foundation.

B2. Calculation of the Specific Heat of Some Alkali Halides. CLARK OLIPHINT, *The Rice Institute.*—A calculation of the specific heat of LiF, KCl, and KI as a function of temperature has been made using Houston's approximation[1] to obtain the frequency spectrum. This frequency spectrum is compared to that calculated from Debye's theory and by the method proposed by Briscoe and Squire.[2] The specific heat as calculated by each method and the experimentally determined specific heat are plotted using Bijl's method[3] and compared. This manner of plotting the curves proves to be quite sensitive in the middle temperature region.

[1] W. V. Houston, Revs. Modern Phys. **20**, 161 (1948).
[2] C. V. Briscoe and C. F. Squire, Phys. Rev. **106**, 1175 (1957).
[3] D. Bijl, Progr. in Low Temp. Phys. **II**, 395 (1957).

B3. Scattering of Acoustic Energy from Solid Metal Spheres in Water.* L. D. HAMPTON AND C. W. HORTON, *The University of Texas.*—This paper presents the results of an experimental investigation of the scattering of acoustic energy from solid aluminum and brass spheres in water when the scattered energy is measured at large distances. Polar diagrams of the distribution in angle of the scattered energy for a range of values of ka from 4.1 to 57 for steady-state conditions are presented. Measurements of target strength for equivalent aluminum and brass spheres are presented for steady-state conditions and also using pulses short enough to measure only the surface reflection. The measured target strengths are compared to theoretical values. The data indicate that the scattering of sound waves from such spheres cannot be described by formulas based on the assumption of a rigid sphere.

* This work was partially supported by Bureau of Ships.

B4. Structural Changes in Copper under Cyclic Stress.* J. C. GROSSKREUTZ, *Midwest Research Institute.*—Small copper samples have been subjected to cyclic stress (pulsating tension) and changes in certain physical properties observed by means of (1) the resonant behavior of the vibrating sample and (2) x-rays scattered at small angles. The resonant frequency of vibration provides a convenient monitor of the stages of fatigue through which the sample is passing. The initial strain hardening is accomplished by a rise in frequency, while fracture is sharply defined by a drop in the frequency. Q^{-1} of the sample is observed to vary during stressing in agreement with other observers.[1] Using techniques already described,[2] the small angle x-ray scattering shows that the most important structural change occurring during stressing is the formation of misoriented subgrains. In contrast to the polygonization caused during static strain, that caused by cyclic strain cannot be removed by a high-temperature anneal. This is attributed to the lack of proper nucleation sites for recrystallization. There is no x-ray evidence to show the production of vacancy clusters in the active slip planes during cyclic cold work.

* Supported by U. S. Air Force through the Materials Laboratory, Wright Air Development Center.
[1] N. Thompson and N. J. Wadsworth, Advances in Phys. **7**, 72 (1958).
[2] J. C. Grosskreutz and F. R. Rollins, J. Appl. Phys. (to be published).

B5. On the Dielectric Constant of Silicon.* ROBERT B. WATSON, ROBERT E. ANDERSON,† AND JAMES C. THOMPSON, *The University of Texas.*—Complex dielectric constant measurements (at a frequency of 24 kMc), Hall voltage measurements, and conductivity measurements have been made on several samples of silicon containing small amounts of impurities. Good internal agreement is found between the values of the dielectric constant and between the values of the conductivity determined by these different measurements. The values of effective masses for holes ($0.3m_0$) and electrons ($0.2m_0$) and of dielectric constant ($K_0=13.7$), agree with values obtained by other investigators.

* Supported by a grant from Texas Instruments, Inc.
† Recipient of post-doctoral fellowship established under the Texas Instruments, Inc. grant to The University of Texas. Now at Texas College of Arts and Industries, Kingsville.

B6. Binding Energy and Lattice Orientation in Small Crystal Carbon Systems. E. I. DOUCETTE, *Bell Telephone Laboratories.*—The binding energy has been calculated for various small crystal carbon and graphite systems for adjacent plane structures using summation and integral methods. A structural transformation has been demonstrated which corresponds to the appearance of three-dimensional order. The lack of three-dimensional ordering in small crystal carbon has been shown to be due solely to the large loss of energy associated with the lateral displacement of adjacent planes accompanying this structure. The apparent lack of planar orientation in small crystals is due to the fact that the relative orientation of adjacent planes is strongly size dependent. The nonhomogeneity of carbons precludes the observation of a single size range, thus prohibiting the determination of the true three-dimensional orientation which actually persists for any given size or planar structure.

B7. Two Phenomena Associated with the Thermal Decomposition and Initiation of α-Lead Azide.* O. H. HILL† AND A. F. WITTENBORN, *Defense Research Laboratory, University of Texas.*—From the results of a general study of the thermal decomposition and initiation properties of α-lead azide, two topics are discussed: (1) Data are presented which show that the memory of the explosive to heat treatment is complete. (2) It is shown that the properties of the azide are markedly influenced by adding to it a metallic diluent. The memory effect and the effect of the metallic diluent are discussed in terms of their relation to the decomposition reaction occurring on the azide crystal surface and the thermal conductivity of the region surrounding the decomposition nuclei.

* Supported by the Engineer Research and Development Laboratories.
† Now at Convair Aircraft Company.

B8. Observation of Precipitates in Gallium Arsenide. D. R. HUFFMAN* AND H. L. TAYLOR, *Texas Instruments Incorporated.*—The Dash technique for observing dislocation patterns in silicon[1] has been investigated for adaptability to crystals of gallium arsenide. It was found possible to decorate imperfections in gallium arsenide by diffusion of either copper, gold, silver, or nickel, with subsequent quenching. A satisfactory combination of diffusion time and temperature for copper is 3 hr at 1140°C. Longer diffusion times are required for gold, silver, and nickel. Different types of structures seem to be decorated by the two most satisfactory precipitates, gold and copper. Comparison of methods and results between gallium arsenide and silicon indicates more severe conditions are required for the former. Precipitate lines are irregularly curved in gallium arsenide compared to short straight lines in silicon. Twin and grain boundaries, not decorated in silicon, have been well marked in gallium arsenide. Some comparison of results between the Dash technique and etch pit methods has been made to indicate the usefulness of the two as tools for studying dislocations in gallium arsenide.

* Now at The Rice Institute, Houston, Texas.
[1] W. C. Dash, J. Appl. Phys. **27**, 1193 (1956).

B9. Effect of Noncylindrical Symmetry on the Paramagnetic Effect in Superconductors. JAMES C. THOMPSON, *The University of Texas.*—When a cylindrical superconductor carries a current and is placed in a longitudinal magnetic field, a paramagnetic permeability is observed at the transition. This effect is believed due to the helical magnetic field produced by current and applied field.[1] The cylindrical symmetry of currents and fields strongly influences the magnitude of the effect. This effect has been recently studied in the presence of a transverse magnetic field. The effect of the transverse field is to cause a linear decrease of the peak paramagnetism without altering the paramagnetism observed on either side of the peak. This effect will be discussed in terms of a simple model.

[1] H. Meissner, Phys. Rev. **97**, 1627 (1955).

B10. Precision Carbon Thermometer for the Liquid Helium Region.* B. J. SANDLIN† AND JAMES C. THOMPSON, *The University of Texas.*—A high precision thermometer system has been developed using a carbon radio resistor (Allen Bradley type) as the sensing element. The resistor is in the frequency determining circuit of a stabilized Wein bridge oscillator. Thus temperature changes are displayed as frequency shifts. The frequency is read directly from a Hewlitt-Packard type 523B counter. When operated in the neighborhood of 100 kc at 4.2°K the sensitivity is approximately 50 kc/deg. This corresponds to a temperature resolution of 20 μdeg, when used with the above counter. Precision can be improved by observing higher harmonics. The power input to the resistor is of the order of 10^{-2} μw. The time for a temperature measurement is 1 sec, and response times to changes are limited only by equilibrium in the thermometer. Absolute accuracy is essentially limited only by the determination of the helium vapor pressure during calibration. Application of this system to the measurement of thermal conductivities will be discussed.

* This work was supported by a grant from Texas Instruments, Inc.
† Texas Instruments Grant Fellow.

B11. Hydrodynamic Drag Force on a Sphere in Liquid Helium.* R. A. LAING AND H. E. RORSCHACH, JR., *The Rice Institute.*—Several spheres of equal radii but different masses were dropped in liquid helium I and II. The terminal velocity of each sphere was determined by measuring the time required for the sphere to fall different distances in the liquid. When falling at constant velocities, the hydrodynamic drag force on each sphere was equal to its weight, and the parameters C_D and n in the formula for the drag force,[1] $D=C_D(\frac{1}{2}\rho v^n)A$, could be evaluated. In this equation, D is the drag force on a sphere of cross-sectional area A moving through the helium of total density ρ at velocity v. Our experiments gave the results $C_D=0.48\pm0.02$ and $n=2.1\pm0.2$ for spheres falling at Reynold's numbers of about 10^6. These parameters showed no observable temperature dependence over the range from 4.2 to 1.7°K. In this region of Reynold's numbers, turbulence exists in the boundary layer and wake of ordinary fluids. One therefore expects turbulence to be present in helium I. Since the same drag force was observed in helium I and helium II, we conclude that at these Reynold's numbers turbulence is present in the superfluid, and the liquid behaves as an ordinary fluid of density $\rho=\rho_n+\rho_s$.

* Supported by a grant from the National Science Foundation.
[1] L. Prandtl and O. G. Tietjens, *Applied Hydro- and Aeromechanics* (Dover Publications, New York, 1957), p. 92.

FRIDAY MORNING AT 10:15

Physics Building, 201

(T. W. BONNER presiding)

Reactions of Transmutation, I

C1. Angular Distributions of Deuterons from the $Be^9(He^3,d)B^{10}$ Reaction at 25 Mev.* H. E. WEGNER AND W. S. HALL, *Los Alamos Scientific Laboratory.*—The angular distribution of deuterons from the $Be^9(He^3,d)B^{10}$ reaction has been measured from 10° to 160° using 25-Mev He^3 ions accelerated in the Los Alamos variable energy cyclotron. A dE/dx and E system of mass separation was employed to detect only the deuterons. The proton contamination in the deuteron spectra was less than one percent. The ground and first four excited states were resolved while higher levels were observed as groups. All of the angular distributions show a marked forward peaking and the resolved levels show diffraction-type structure in the forward angular region characteristic of Butler stripping and surface interaction phenomena. The distributions beyond 90° are relatively flat and show little structure which is more characteristic of compound nucleus processes. The resolved levels are all of even parity and show minima at 30° and 55° and maxima at 40° and approximately 70° in the center-of-mass system. The angular distributions of the unresolved groups of levels show little diffraction-type structure since the parities of the involved levels are mixed.

* Work done under the auspices of the U. S. Atomic Energy Commission.

C2. Search for Excited States of He^5.* R. BASS, T. W. BONNER, E. A. DAVIS, F. GABBARD, AND T. RETZ-SCHMIDT, *The Rice Institute.*—Previous experiments[1] using a helium filled ionization chamber showed a narrow resonance in the scattering of 22.15 Mev neutrons by He^4 which corresponds to an excited state in He^5 at 16.72 Mev. The present experiments were carried out in the energy range of 5.5 to 16 Mev to search for other possible resonances. Several nuclear reactions were used in order to cover this energy range. They include the following: $D(d,n)He^3$, $T(d,n)He^4$, $N^{14}(d,n)O^{15}$, and $N^{15}(d,n)O^{16}$. Pulse-size distributions obtained with a 256-channel analyzer showed a prominent peak corresponding to small angle scattering of the neutrons and also a peak due to backward scattering. Differential cross sections for scattering through angles of 102° to 180° were obtained. No resonances were observed and the scattering cross section decreases slowly with increasing energy of the neutrons.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Bonner, Prosser, and Slattery, Bull. Am. Phys. Soc. Ser. II, 2, 180 (1957).

C3. $Li^6(He^3,n)B^8$ Reaction.* B. J. FARMER AND C. M. CLASS, *The Rice Institute.*—The counter ratio method[1] has been used to determine the neutron threshold energies in the $Li^6(He^3,n)B^8$ reaction for the formation of B^8 in its ground state and first excited state. The threshold energies for these states are, respectively, 2.974 ± 0.010 Mev and 4.159 ± 0.030 Mev. These values establish the mass excess of B^8 to be $27\,161\pm10$ uMu and locate the first excited state of B^8 at 0.789 ± 30 Mev. The half-life of B^8 was determined to be 0.79 ± 0.02 sec. A comparison measurement of the Li^8 half-life gave 0.84 ± 0.02 sec. The excitation function for the reaction for bombarding energies between 2.9 and 5.5 Mev was also determined by measuring the yield of the positrons from the decay of B^8. Since B^8 is unstable to Be^7+p above an excitation energy of 133 kev, the yield of positrons measures the formation of B^8 in its ground state only. The excitation function is linear with energy in the interval from 3.4 to 5.5 Mev, and the cross section for the reaction at 5.0 Mev is 20 mb.

* Supported in part by the U. S. Atomic Energy Commission.
[1] T. W. Bonner and C. F. Cook, Phys. Rev. 96, 122 (1954).

C4. Low Excited States in Be^9 and B^9.* R. R. SPENCER† AND G. C. PHILLIPS, *The Rice Institute.*—The low excited state region of Be^9 and B^9 have been investigated by magnetic analysis of the reaction $Be(p,p)Be^9$ and $B^{10}(He^3,\alpha)B^9$ using the Rice Institute Van de Graaff and the annular magnet spectrometer. The energies of excitation and widths of states observed in Be^9 were 0 Mev, 2.430 ± 0.005 Mev ($\Gamma\leqslant 5$ kev), and 3.04 ± 0.05 Mev ($\Gamma=250\pm50$ kev). In addition a cusp was observed at 1.674 ± 0.005 Mev very near the neutron threshold. For B^9 the states observed were at excitations of 0 Mev, 2.39 ± 0.01 Mev ($\Gamma=83\pm9$ kev), and 2.79 ± 0.05 Mev ($\Gamma=700\pm200$ kev). A continuum in the B^9 spectra was observed for all excitations greater than the sharp "ground state" 0 Mev, suggesting that there may be states of B^9 below the sharp ground state that are greatly suppressed by the Coulomb barrier for proton emission. When corrected for the barrier this continuum suggests that B^9 may have a cusp also. In addition to presenting the spectra of the two nuclei, evidence will be given that the 2.43 to 2.33 and 3.04 to 2.79 Mev mirror pair of states in Be^9 and B^9 are very pure two body states consisting of a proton or neutron interacting with the 2.9 Mev, 2^+, excited state of Be^8.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Phillips Petroleum Company, Idaho Falls, Idaho.

C5. Disintegration of B^{10} by Neutrons.* E. A. DAVIS, R. BASS, T. W. BONNER, F. GABBARD, AND T. RETZ-SCHMIDT, *The Rice Institute.*—Previous measurements[1] of the total (n,α) cross section for disintegration of B^{10} showed resonances at 0.53, 1.86, 2.8, and 4.1 Mev. Measurements of the (n,α) cross section made with a grid ionization-chamber using fast collection and giving much better resolution ($\sim$6%) allow the separation of the disintegrations leading to the ground state and first excited states of Li^7. At thermal energies, about 93% of the disintegrations proceed to the first excited state while only about 7% go to the ground state of Li^7. The ratio of the intensity of the ground state group to the first excited state group increases monotonically from thermal to a value of 48% at a neutron energy of 810 kev. The resonance at a neutron energy of 0.53 Mev was observed in both the ground state and first excited state groups. Experiments are being continued on the (n,α) disintegration at higher neutron energies where the competing reactions will also be studied.

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. Bichsel and T. W. Bonner, Phys. Rev. 108, 1025 (1957); Petree, Johnson, and Miller, Phys. Rev. 83, 1148 (1951).

C6. Absolute Determination of the $C^{13}(p,n)N^{13}$ Neutron Threshold.* EVERET H. BECKNER AND RICHARD L. BRAMBLETT, *The Rice Institute.*—The Rice Institute 5.5-Mev Van de Graaff accelerator is being used in conjunction with the 180° magnetic spectrometer and a polyethylene sphere neutron counter to make absolute determinations of the $C^{13}(p,n)N^{13}$ neutron threshold. The polyethylene sphere counter employs a Li^6I crystal for detection of the neutrons. A 68% C^{13} foil is supported within the gap of the spectrometer

and the elastic protons fron C^{13} are detected in the spectrometer to provide an accurate calibration of the bombarding proton energy. Simultaneous detection of these elastically scattered protons and the threshold neutrons then permits an accurate absolute determination of the $C^{13}(p,n)N^{13}$ threshold. Furthermore, it is possible to accomplish simultaneous detection of the elastic protons from C^{13} and C^{12} in the spectrometer, permitting the determination of the presence and thickness of target contamination, if such is present. Employing these methods a preliminary value of 3.230 ± 0.004 Mev has been determined for the $C^{13}(p,n)N^{13}$ neutron threshold.

* Supported in part by the U. S. Atomic Energy Commission.

C7. Energy Levels in N^{14} from the $C^{13}(p,p)C^{13}$ and the $C^{13}(d,d)C^{13}$ Reactions.* E. KASHY, R. R. PERRY, AND J. R. RISSER, *The Rice Institute.*—The elastic scattering cross section for $C^{13}(p,p)C^{13}$ was measured from 2.5 to 4.5 Mev, using a self-supporting target of carbon enriched to 67% carbon-13. Data were taken at center-of-mass angles of 39.2, 90.0, 125.3, 155.0, and 162.6 degrees. Resonances were observed corresponding to states at 10.20, 10.44, 11.05, 11.26, 11.3, and 11.42 Mev in N^{14}. The elastic scattering cross section for $C^{13}(d,d)C^{13}$ was measured at center-of-mass angles of 45.0, 87.5, 131.4, 161.8, and 167.5 degrees from 0.5 to 1.5 Mev. The target used was a thin self-supporting C^{13} foil. Resonances were observed corresponding to states in N^{14} at 11.05, 11.3, 11.38, and 11.49 Mev. The analysis of the data is in progress using the dispersion theory form of the scattering matrix.

* Supported in part by the U. S. Atomic Energy Commission.

C8. Proton Capture in C^{14} and O^{18}.* J. D. HENDERSON, J. W. NELSON, AND EMMETT L. HUDSPETH, *The University of Texas.*—The excitation function for $C^{14}(p,\gamma)$ was observed at 90° with a 3- by 3-in. NaI crystal and a 4.6- to 12.6-Mev window. Bombarding energies were determined from readings of a NMR gaussmeter. Resonances at $E_p=2.08$, 2.27, and 2.90 Mev were found; these agree with data[1] on $C^{14}(p,n)$. A resonance at 2.48 Mev is broader than a corresponding resonance in the $C^{14}(p,n)$ work and may actually be unresolved. The excitation function for $O^{18}(p,\gamma)$ has also been taken with approximately 8 to 10 Mev and with 6 to 8 Mev sliding windows. Resonances were tentatively established in a ZrO_2[18] target at proton energies of (±5 kev) 1.759, 1.924, 2.256, 2.379, 2.629, and 2.757 Mev in the 8 to 10 Mev counts and at 1.685, 1.764, 1.921, 2.256, 2.365, 2.430, 2.642, and 2.766 Mev in the 6 to 8 Mev counts. In each case there are indications of other weaker resonances. These results will be discussed with respect to the earlier work[2] below $E_p=2$ Mev and with observations[3] on $O^{18}(p,\alpha)$ and $O^{18}(p,n)$.

* Assisted by the U. S. Atomic Energy Commission.
[1] R. M. Sanders, Phys. Rev. **104**, 1934 (1956).
[2] J. W. Butler and H. D. Holmgren, Phys. Rev. **99**, 1649A (1955).
[3] H. A. Hill and J. M. Blair, Phys. Rev. **104**, 198 (1956).

C9. Excited States in F^{18} from $O^{16}(He^3,p)F^{18}$.* D. A. A. S. N. RAO,† T. E. YOUNG, R. R. SPENCER, EVERET H. BECKNER, AND G. C. PHILLIPS, *The Rice Institute.*—The reaction $O^{16}(He^3,p)F^{18}$ has been investigated using the Rice Institute 5.5-Mev Van de Graaff as a source of He^{3+} ions and the reaction protons have been analyzed in the 180° magnetic spectrometer. The following excited states in F^{18} have been identified: 0.943, 1.049, 1.089, 1.130, 1.708, 2.102, 2.521, 3.058, 3.130, 3.360, 3.724, and 3.843. All excitation energies are accurate to ±10 kev. The identification of some of these states and their comparison with the shell model predictions will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
† Texas Southern University, Houston, Texas.

C10. Gamma Radiation from $O^{18}(p,n\gamma)F^{18}$.* T. RABSON, W. D. BARFIELD, T. W. BONNER, AND H. HAENNI, *The Rice Institute.*—Gamma radiations with energies less than 2 Mev were observed when a 12.7 mg/cm² thorium foil, which had been heated in an atmosphere of heavy water enriched in O^{18} (85%), was bombarded with protons. Gamma-ray energies above 0.500 Mev were observed by analyzing the photoconversion electrons from the above target in an intermediate-image magnetic lens spectrometer. Gamma-ray energies of 0.670, 0.940, 1.039, and 1.081 Mev were observed. The relative intensity of the 0.940-, 1.039-, and 1.081-Mev gamma radiations vary by large amounts as the proton energy is increased from 3.9 Mev to 4.6 Mev. The low-energy gamma radiation from this same target was observed by means of a NaI crystal at several bombarding energies and a 0.180-Mev gamma ray was seen at an incident proton energy of 4.25 Mev. Experiments are being carried out to measure the internal conversion coefficients of the low-energy radiations.

* Supported in part by the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Batts Auditorium

(N. E. BRADBURY presiding)

Invited Papers

E1. Recent Progress in Primary Cosmic Radiation and the Origin of the High-Intensity Belt around the Earth. MANUEL SANDOVAL VALLARTA, *Instituto Nacional de la Investigacion Cientifica, Mexico.*

E2. Recent Work on Radiation Widths on Neutron Resonances. B. B. KINSEY, *University of Texas.* (30 min.)

E3. Thermonuclear Machines as of the 1958 Geneva Conference. WILLIAM P. ALLIS, *M. I. T.* (40 min.)

E4. Production of Very Large Magnetic Fields by Implosion. C. M. FOWLER, *Los Alamos Scientific Laboratory.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Physics Building, 201

(N. D. SMITH presiding)

Invited Papers

F1. Medium Energy Electron Scattering. L. MARTON, *National Bureau of Standards.* (30 min.)

F2. Resolution of Overthrust Fault Paradox by Application of Archimedes' Principle. M. KING HUBBERT, *Shell Development Company.* (30 min.)

F3. Phase Transformations Induced by Shock Waves in Solids. D. S. HUGHES, *University of Texas.* (30 min.)

F4. Recent Applications of Ultrasonic and Hypersonic Waves in Solid State Physics. H. E. BOMMEL, *Bell Telephone Laboratories.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Physics Building, 203

(W. W. HAVENS, JR., presiding)

Reactions of Transmutation, II

G1. Study of the Reaction $Ne^{20}(n,\alpha)O^{17}$.* F. GABBARD, R. J. BELL,† AND T. W. BONNER, *The Rice Institute.*—A neon filled grid-type ionization chamber was used to study the alpha particles emitted upon bombardment of neon with fast neutrons. The neutrons were monitored with a "long counter" which was calibrated with a standard Ra−Be source and the absolute (n,α) cross section was determined. Neutron sources used were the $T(p,n)He^4$ and $D(d,n)He^3$ covering an energy range from 2.8 to 7.3 Mev. Experimental resolution was about 25 kev for the Zr−T target and varied from 95 kev to 55 kev for the deuterium gas target. The cross section for disintegrations by alpha emission leading to the ground state and first excited states of O^{17} was measured as a function of neutron energy. Resonances in the cross section were observed at neutron energies (Mev) of 2.89, 3.19, 3.29, 3.52, 3.60, 3.70, 3.87, 4.15, 4.31, 4.63, 4.98, 4.52, 5.93, 6.33, 6.60, and 6.93. The total (n,α) cross section varies from 10 mb to 270 mb in this energy range.

* Supported in part by U. S. Atomic Energy Commission.
† Now at Virginia Polytechnic Institute.

G2. Fast Neutron Activation of Al.* O. M. HUDSON, JR., AND IRA L. MORGAN, *Texas Nuclear Corporation.*—A study of the $Al^{27}(n,p)Mg^{27}$ reaction has been made in the energy region of 13.0 Mev to 17.0 Mev. The relative excitation curve was measured in approximately 100 kev intervals and normalized to absolute cross-section measurements at 13.3 Mev, 13.9 Mev, and 15.3 Mev. A calibrated NaI(Tl) well counter was used to measure the delayed gamma radiation which results from the decay of Mg^{27}. The decay was followed for several half-lives. The cross section for the $Al^{27}(n,p)Mg^{27}$ reaction decreases from 100 ± 12 mb at $E_n=13.0$ Mev to 55 ± 6 mb at $E_n=17.0$ Mev. The cross section at 14.0 Mev agrees well with previous measurements.[1,2]

* This work was supported by the Modern Physics Research Branch, Aeronautical Research Laboratory, Wright Air Development Center.
[1] Haling, Peck, and Eubank, Phys. Rev. **106**, 971 (1957).
[2] Stuart G. Forbes, Phys. Rev. **88**, 1309 (1952).

G3. Investigation of the $K^{39}(n,p)$ and $K^{39}(n,\alpha)$ Reactions.* H. HAENNI, R. BASS, T. W. BONNER, R. H. DAVIS, F. GABBARD, AND T. RETZ-SCHMIDT, *The Rice Institute.*—A KI(Tl)-crystal (6 mm in diameter and 6 mm thick) was used to observe the (n,p) and (n,α) reactions. The crystal was mounted on a photomultiplier tube and the spectrum was studied with a 256 channel analyzer. The neutrons were produced with the $Li(p,n)$ reaction, using thin targets. The proton group resulting from formation of A^{39} in the ground state shows the greatest cross section for neutrons with energies of from 0.85 to 3.0 Mev. The cross section of this group has been studied in detail and the excitation curve shows many narrow resonances. The experiments are being continued at higher neutron energies where several groups of protons and alpha particles are observed.

* Supported in part by the U. S. Atomic Energy Commission.

G4. $Ca^{40}(p,p')Ca^{40}$ Reaction.* J. H. JOHNSON AND C. M. CLASS, *The Rice Institute.*—The elastic and inelastic proton groups from the $Ca^{40}+p$ reaction have been studied for bombarding energies between 4.5 and 5.5 Mev using a CsI crystal spectrometer. Thin targets (~3 kev) were prepared by evaporating calcium onto 80 $\mu g/cm^2$ thick carbon supporting foils. Energies were assigned to the inelastic groups by comparison with the accurately known energy of the elastic protons. States in Sc^{41} which decayed to the 0^+, first excited state of Ca^{40} at 3.35 Mev were found at $Ep=5.02$, 5.08, and 5.25 Mev.[1] From the line shape analysis of the corresponding elastic protons, these states are identified as $\frac{1}{2}^+$. Other states in Sc^{41} at $Ep=5.39$, 5.41, and 5.45 Mev, possessing elastic resonance shapes compatible with formation by $l=2$ protons, decayed with approximately equal intensities to the first excited state of Ca^{40} and to the known second excited state at 3.73 Mev. A level at $Ep=5.43$ Mev, formed probably by $l=3$ protons, decayed only to the second excited state of Ca^{40}. These data together with the relative penetrabilities for the inelastically scattered protons suggest a spin assignment of 2^+ for the 3.73 Mev state in Ca^{40}.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. D. Bent and T. H. Kruse, Phys. Rev. **109**, 1240 (1958).

G5. Low-Energy Gamma Radiations from Thermal Neutron Capture in Silver and Antimony. D. L. EDENS, W. G. CANTRELL, O. T. GOINES, G. N. SALAITA, AND AMBUJ MUKERJI, *A and M College of Texas.*—Production of prominent gamma rays of energy 69, 110, and 196 kev in silver and 75,

115, 150, and 325 kev in antimony by thermal neutron capture has been reported previously.[1] Silver and antimony disks were irradiated by thermal neutrons from a Pu−Be source of flux 3.44×10^6 neutrons per sec in this laboratory. The detecting arrangement for the gamma rays consisted of a 2-in. diameter and 2-in. thick NaI(Tl) crystal along with a 256-channel pulse-height analyzer. From the geometry of the experiment correcting for the efficiency of the detector, it was concluded that less than one quantum of each of the radiations listed above is produced per hundred thermal neutron captures. The results of the experiments on these gamma rays by placing the samples in the graphite thermal column of the AGN-201 nuclear reactor will be presented.

[1] J. E. Draper and C. K. Bockelman, Bull. Am. Phys. Soc. Ser. II, 3, 177 (1958).

G6. Coulomb Excitation of Osmium.* F. E. DURHAM, D. H. RESTER, AND C. M. CLASS, *The Rice Institute.*—The spectrum of internal conversion electrons from the Coulomb excitation of natural osmium with both protons and alpha particles has been obtained with a magnetic spectrometer. The principal results on the even-even isotopes are summarized in Table I. In addition, electron peaks corresponding to the

TABLE I.

Isotopic mass	Transition energy (kev)	$[B(E2)]\exp(e^2\times10^{-48}\ \text{cm}^4)$	$K:L:M$
186	136.3	5.1	...
188	155.1	3.5	1.0:1:0.27
190	187.0	3.0	1.4:1:0.33
192	205.7	2.3	1.4:1:0.39

L_{I+II}, L_{III}, and M lines for a 69-kev transition were observed with relative intensities of 2.2:1:1.1, indicating $E2/M1=0.25$. The measured excitation curve agrees with $E2$, $\Delta E=69$ kev. This level is assigned to the 16% abundant isotope Os^{190}; the $B(E2)e^2$ value for its excitation is $1.2b^2$. Another weak line at an electron energy of 120.0±0.5 kev, also believed due to Os^{190}, was found to excite like a state between 120 and 200 kev. The other lines from this transition were obscured by the more intense part of the spectrum.

* Supported in part by the U. S. Atomic Energy Commission.

G7. Anomalous Character of the Second Coulomb Excited State in Th^{232}.* D. H. RESTER, F. E. DURHAM, AND C. M. CLASS, *The Rice Institute.*—Measurements on internal conversion electrons resulting from Coulomb excitation of Th^{232} are not easily reconciled with the γ-ray measurements. Conversion electron lines have been observed for only one transition, having an energy of 725±4 kev.[1,2] These lines excite in agreement with either an $E1$ or $E2$ transition to a state at 775±75 kev.[2] The measured $K:L+M$ ratio of 3.5[1,2] is compatible with a pure multipole of order no greater than one. On the other hand, two γ rays are reported which are assigned to transitions from a 790 (2^+) level to the ground state and to the 50 kev first 2^+ state. The evidence on the 740-kev γ ray—identified with the electron transition—indicates $E2$ character, although a predominantly $M1$ transition is not excluded.[2] Two alternatives can be considered: (1) the transition is nearly pure $M1$ (further supported by estimates of the conversion coefficient)[2,3] or (2) the $2^+\rightarrow2^+$ transition has a strong monopole admixture. There are serious theoretical objections to both alternatives; the discrepancy in the energies assigned to the transitions remains.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Moore, Class, Prosser, and Schiffer, Bull. Am. Phys. Soc. Ser. II, 1, 88 (1956).
[2] M. V. Harlow, Thesis, The Rice Institute (1958).
[3] F. K. McGowan, paper given at the Paris Conference (1958).

G8. Fission Yields as Vectors. GEORGE P. FORD,* *University of California, Los Alamos Scientific Laboratory.*—Turkevich and Niday[1] have suggested there are two different modes of fission with mass yield characteristics that explain the increase in proportion of symmetric fissions with increasing excitation energy. Mass yields for U^{238} γ fission, Th^{232} proton fission, U^{238} α fission, and normal uranium deuteron fission have been examined in terms of vector spaces for consistency with their hypothesis. The first three cases are on the whole consistent with the hypothesis while the fourth is not because the measured yields include some yields from neutron fission. Some consequences of the hypothesis with the requirement for nonnegative yields and nonnegative coordinates are derived.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] A. Turkevich and J. B. Niday, Phys. Rev. 84, 52 (1951).

Invited Paper

G9. Some Recent Developments in Fission Physics. J. J. GRIFFIN, *Los Alamos Scientific Laboratory.* (30 min.)

FRIDAY EVENING AT 7:00

Crystal Room, Hotel Driskill

(G. E. UHLENBECK presiding)

Banquet of the American Physical Society

After-dinner speakers to be announced.

SATURDAY MORNING AT 9:30

Batts Auditorium

(W. V. HOUSTON presiding)

Invited Papers in Cryogenics

J1. Ten Years of Helium-3 Research. E. C. KERR, *Los Alamos Scientific Laboratory.* (30 min.)

J2. Excitations in Liquid Helium. J. L. YARNELL, *Los Alamos Scientific Laboratory.* (30 min.)

J3. Some Hydrodynamic Properties of Liquid Helium at Large Reynold's Numbers. H. E. RORSCHACH, JR., *The Rice Institute.* (30 min.)

J4. Studies in Magnetism at Temperatures below 1°K. C. F. SQUIRE, *The Rice Institute.* (30 min.)

SATURDAY MORNING AT 9:30

Physics Building, 201

(G. E. UHLENBECK presiding)

Invited Papers in Nuclear Physics

K1. Application of Reaction Studies to Nuclear Spectroscopy. W. W. BUECHNER, *M. I. T.* (30 min.)

K2. Evidence from Scattering Data for Two-Body Interactions in Light Nuclei. G. C. PHILLIPS, *The Rice Institute.* (30 min.)

K3. Direct Emission in the Nuclear Photoeffect. J. S. LEVINGER, *Louisiana State University.* (30 min.)

K4. Numerical Calculations of Polarization and Cross Sections in Deuteron Stripping Reactions. W. TOBOCMAN, *The Rice Institute.* (30 min.)

SATURDAY MORNING AT 9:30

Physics Building, 203

(E. L. HUDSPETH presiding)

General Nuclear Physics; Magnetic Resonance

L1. Radiations from Ni^{65}. G. N. SALAITA, W. G. CANTRELL, D. L. EDENS, O. T. GOINES, AND AMBUJ MUKERJI, *A and M College of Texas.*—Ni^{65} was produced by irradiating pure nickel bar in the "glory-hole" of the AGN-201 nuclear reactor. The gamma- and beta-ray spectra emitted from the sample were investigated by scintillation spectrometer employing a 256-channel pulse-height analyzer. For the detection of the gamma radiations a 3-in. diam and 3-in. thick NaI (*TL*) crystal was used. The beta-ray detector consisted of a 2-mm thick anthracene crystal. Photoelectric peaks decaying with 2.56 *h* half-life corresponding to Ni^{65} were observed at 1460±20 kev, 1100±20 kev, and 370±5 kev. The relative intensity of the corresponding gamma radiations is 56:38:6. Two other peaks at gamma-ray energies of 810 and 510 kev were also observed but these peaks decayed with a much longer half-life. They are assigned to Co^{58} produced by the (n,p) reaction in nickel. Results of the beta-gamma and gamma-gamma coincidences along with the decay scheme of Ni^{65} will be presented.

L2. Decay of Pd^{109} and Pd^{109m}. J. W. STARNER, *Los Alamos Scientific Laboratory** (introduced by M. E. Bunker).—The radiations of Pd^{109} (13.45±0.01 hr) and Pd^{109m} (4.69±0.01 min) have been investigated with a coincidence scintillation spectrometer and a solenoidal beta-ray spectrometer. Pd^{109m} was observed to have only one mode of decay: a 188-kev (*E3*) isomeric transition to Pd^{109}. The principal beta-ray group (>99.9%) of Pd^{109} was found to have an end-point energy of 1.030±0.005 Mev. Gamma rays of the following energies (kev) and approximate intensities (photons/10^6 disintegrations) were observed to accompany the decay of Pd^{109}: 773 (4), 707 (2), 643 (10), 601 (2), 553 (2), 448 (1), 412 (10), 325 (0.5), 307 (10), 129 (0.5), 88 (6×10^3), and 41 (1). The following gamma-gamma coincidences were observed: 643–129, 601–129, 601–41, 553–307, 448–412, 412–307 kev. A level scheme is proposed which involves energy levels at 88, 129, 307, 412, 719, 732, and 860 kev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

L3. Some Properties of Residual Gamma-Radiation Fields Following Nuclear Detonations. ROBERT L. MATHER, *U. S. Naval Radiological Defense Laboratory.*—The two principal types of residual gamma-radiation fields following nuclear detonations result from deposited fallout activities (principally fission products) and induced activities produced by neutron reactions in the soil near ground zero. About 80% of the biological effectiveness of the "fallout" field and about 54% of the "induced" field are due to the direct, unscattered, gamma radiation from the source distributions. Various significant

properties of the resulting fields can be computed on the basis of simple exponential attenuation of the gamma rays from the sources. Exemplary results on angular distribution, distance to contributing sources, and change of intensity with height will be shown.

L4. Quenching of Positronium Lifetimes by Molecular Iodine.* C. R. HATCHER† AND W. E. MILLETT, *The University of Texas.*— Measurements of the mean life of the τ_2 component for decay in solutions of iodine in normal heptane give a value of 10^{-17} cm³ for the cross section of molecular iodine for annihilating ^3S positronium on collision. This effect is attributed to an enhancement of "pickoff" annihilation resulting from either a tendency to form positronium iodide or the high polarizability of molecular iodine. In quenching τ_2 from 2.49×10^{-9} sec to 1.32×10^{-9} sec the intensity I_2 of the long component was observed to vary over a range from 40% to 27%; however, the errors in I_2 are so large for the shorter lifetimes that it is impossible to tell from the data whether or not I_2 is influenced by the presence of iodine.

* Supported in part by the U. S. Air Force Office of Scientific Research and in part by The University of Texas Research Institute.
† Now at the Lawrence Radiation Laboratory.

L5. Annihilation of Positrons in Organic Liquids.* T. W. FALCONER,† C. R. HATCHER,‡ AND W. E. MILLETT, *The University of Texas.*—The mean life τ_2 and fraction I_2 of positrons which form ^3S positronium have been measured for annihilation in 20 organic liquids—alcohols, glycols, acids, benzene derivatives, and others. By using the measured value of τ_2, it is possible to calculate σv where σ is the molecular cross section for annihilating ^3S positronium on collision and v is the average velocity of the positronium atom. The results show that in general σv is related to the "size" of the molecule although there are some consistent exceptions to this rule. There is also a rough correlation between τ_2 and density, τ_2 being shortest for the most dense liquids and longest for the least dense ones.

* Supported in part by The U. S. Air Force Office of Scientific Research and in part by The University of Texas Research Institute.
† Now with Texas Instruments, Inc.
‡ Now at the Lawrence Radiation Laboratory.

L6. New Energy-Sensitive Neutron Counter.* RICHARD L. BRAMBLETT, R. I. EWING, AND T. W. BONNER, *The Rice Institute.*—The efficiency of a gamma-ray insensitive neutron counter has been measured from 0.025 to 7.00 Mev neutron energy using monoenergetic neutrons produced with a Van de Graaff accelerator. A small Li^6I scintillator mounted on a ¼-in. diam polystyrene light pipe was placed at the centers of polyethylene moderating spheres of various sizes, ranging from 2 to 12 in. in diam. For the smaller spheres, the efficiency is greatest for low neutron energy and decreases rapidly as the neutron energy is increased. With the larger spheres the counter is less efficient at low neutron energy due to capture, and the efficiency initially increases, reaches a maximum, and finally decreases. For the 5- and 8-in. spheres, the maxima occur at 0.3 and 1.5 Mev; and the maximum for the 12-in. sphere is estimated to be at 8 Mev. At 500 kev the efficiencies of the 2- and 12-in. spheres are such that a 10-kev change in the energy of a monoenergetic group of neutrons results in a 2.6% change in the ratio of the count rates. This counter has been used to measure the most probable energy of the evaporation spectrum resulting from inelastic scattering of neutrons from heavy nuclei. The efficiency curves are such that most probable energies as low as 100 kev can be measured.

* Supported in part by the U. S. Atomic Energy Commission.

L7. Method for Rapid Transport of Neutron Irradiated Samples.* CLAUDE F. WILLIAMSON AND JOSEPH T. PEOPLES, *University of Texas.*—A method has been devised for the transit of neutron irradiated samples over many feet in a fraction of a second. The sample is moved from irradiation position to counting position through polyethylene or Tygon tubing by compressed nitrogen. Plastic tubing is used to allow the sample to be moved around corners without jamming. The pressure is controlled by a manifold of four solenoid valves to allow movement of the sample back and forth from counting to irradiation position. The beam interrupter of the Van de Graaff accelerator can also be actuated by the switch that controls the solenoid valves. The time required to move a 1-g pellet of beryllium metal through 35 ft of ¼-in. i.d. polyethylene tubing with a head pressure of 100 psig has been measured at 0.42 sec with a photoelectric light beam interrupter; the time to travel 18 ft in Tygon tubing was measured as 0.28 sec. Coiling the tubing through radii as small as 24 in. causes no appreciable increase in transit time. Liquid and gas samples could presumably be transported if they were properly encapsulated. This device should be useful in the study of very short-lived activities induced by neutron bombardment.

* Assisted by the U. S. Atomic Energy Commission.

L8. Precision Capacitor Divider Method for Measuring High Voltages. I. T. MYERS AND H. V. LARSON, *General Electric Company.**—A precision capacitor divider method was developed for measuring high voltages with negligible loading of the voltage source. The equipment consists of an induction plate which "sees" the high voltage terminal, a low leakage polystyrene dielectric condenser, a vibrating reed electrometer with recorder, and a type K-2 potentiometer. In operation, the vibrating reed electrometer is used to measure the charge on the low leakage condenser, which is the same as the charge on the induction plate. High precision is obtained by using the potentiometer in the feedback loop of the electrometer; the electrometer operates as a null detector. The method was used on a 2-Mev electron Van de Graaff accelerator, with the induction plate being mounted inside the pressure tank. The system was calibrated with the Be (γ,n) threshold reaction, for which the reproducibility was about $\pm0.05\%$. Departures from linearity were measured using a total beam calorimeter and a beam current integrator, and were found to be less than the calorimetric error of about 1%.

* This paper is based on work performed for the U. S. Atomic Energy Commission.

L9. Nuclear Magnetic Resonance of Solid Hydrogen.* GEORGE W. SMITH, *The Rice Institute.*—Nuclear magnetic resonance studies of solid hydrogen are being conducted at temperatures below 1°K by means of the technique of magnetic cooling. The central peak in the solid hydrogen complex line has been observed to disappear at low enough temperatures. Experimental work pointed toward a search for splitting in the resonance of solid deuterium will be discussed.

* Supported in part by a grant from the Robert A. Welch Foundation.

L10. Proton Spin Relaxation in Aqueous Solutions of Paramagnetic Ions. II. Cr^{+++}, Mn^{++}, Ni^{++}, Cu^{++}, and Gd^{+++}.* L. O. MORGAN AND A. W. NOLLE, *The University of Texas.*—Nuclear magnetic relaxation times of protons in aqueous solutions of chronic, manganous, nickel, cupric, and gadolinium salt solutions were measured as a function of proton resonance frequency in the range 1.9 to 60 Mc/sec. In most respects the results may be explained adequately in terms of the Solomon[1] formulation of electron-nuclear dipole-dipole interaction and Bloembergen's[2] expression for scalar coupling of electron and nuclear spins. Proton relaxation in nickel, cupric, and gadolinium ion solutions is dominated by dipole-dipole interaction, while isotropic spin exchange contributes heavily to spin-spin relaxation in manganous ion solutions and, perhaps, in chromic ion solutions. At high proton resonance frequencies (large magnetic field strengths) T_1 and T_2 values

are lower than those expected theoretically on the basis of low field values, suggesting that polarization of the paramagnetic species occurs in high fields. Among the ions studied, nickel is unique in that the appropriate correlation time for dipole-dipole interaction is the electron spin relaxation time rather than the tumbling time of the aquated paramagnetic ion.

* This work was done under grants from the Robert A. Welch Foundation, and the Office of Naval Research.
[1] I. Solomon, Phys. Rev. **99**, 559 (1955).
[2] N. Bloembergen, J. Chem. Phys. **27**, 572 (1957).

L11. Nuclear Magnetic Relaxation in Alkali Halide Crystals.* W. E. BLUMBERG, *University of California, Berkeley.*—Nuclear relaxation in ionic crystals has been studied theoretically by Van Kranendonk,[1] who attributed the relaxation to the interaction of the nuclear quadrupole moment with time dependent field gradients arising from motion of the ions due to lattice vibrations. This calculation has been extended, in the case of alkali halide crystals, to include another source of time dependent field gradients, arising from the electric dipole polarization of the ions. The field gradient at the X nuclear site due to a dipole moment induced in the Y ionic shell by a relative displacement of the X and Y ions is shown to be comparable to the electric field gradient produced by the motion of the Y ion itself. Computations combining the two effects have been carried out for the Cl and Br salts of Na, K, and Rb using the quadrupole antishielding factors calculated by Wikner and Das.[2] The results agree well with the measured relaxation times reported by Wikner and Hahn[3] and the following experimental results. RbCl: $T_1(\mathrm{Rb}^{87})=240$ msec, RbBr: $T_1(\mathrm{Br}^{79})=32$ msec, $T_1(\mathrm{Br}^{81})=45$ msec, $T_1(\mathrm{Rb}^{87})=160$ msec.

* Supported in part by the Office of Naval Research and the U. S. National Security Agency.
[1] J. Van Kranendonk, Physica **20**, 781 (1954).
[2] E. G. Wikner and T. P. Das, Phys. Rev. **109**, 360 (1958).
[3] E. G. Wikner and E. L. Hahn, Bull. Am. Phys. Soc. Ser. II, **3**, 325 (1958).

L12. Polarization in the NMR Spectra of Disubstituted Benzenes. P. L. CORIO, J. S. MARTIN, AND B. P. DAILEY, *Columbia University.*—The chemical shifts of the ring protons of a number of substituted toluenes have been studied with a high resolution nuclear magnetic resonance spectrometer similar in design to the Varian Model 4300. The spectrometer was operated at frequencies of 30 Mc and 60 Mc. Samples were studied in dilute cyclohexane solutions. The proton magnetic resonance spectra of the ring protons in monosubstituted benzenes suggest that those molecules must be polarized before selective substitution reactions can take place. The spectrum of toluene, for example, is a single line. In the substituted toluenes the ring protons still have nearly identical chemical shifts in an individual molecule but the magnitude of the chemical shift varies as the second substituent takes up ring positions ortho, meta, and para to the methyl group. The proton chemical shifts indicate that the substituent transferred charge to the ring to an extent which depends on the polarized arrangement of charge on the ring as the substituent approaches. The amount of charge transferred to the ring varied as follows: $m>p>0$; $\mathrm{OH}>\mathrm{F}>\mathrm{CH_3}>\mathrm{Cl}$. Molecular orbital calculations of polarization effects in aromatic compounds are in agreement with these experimental results.

SATURDAY AFTERNOON AT 1:30

Batts Auditorium

(L. C. BIEDENHARN presiding)

Gaseous Electronics; Theoretical Physics; General Physics

N1. Pulse Formation In Geiger Counters. P. F. LITTLE, *University of Oklahoma* (introduced by R. G. Fowler).—It has been suggested that resonance radiation and metastable atoms are important in halogen quenched Geiger counters. Theoretical values of the time delays have been derived, and oscillations in the counters are discussed.

N2. Observations on a Deuterium Plasma Compressed by an Axial Magnetic Field.* K. BOYER, W. C. ELMORE, E. M. LITTLE, AND W. E. QUINN, *Los Alamos Scientific Laboratory.*—A rapidly rising magnetic field is used to ionize and compress a deuterium plasma in a cylindrical mirror geometry. A shaped single-turn coil with a mirror ratio of 1.3 is energized from a 100-kv, 8.8-μf capacitor bank.[1] The system inductance allows half the capacitor voltage to appear across the coil terminals. With the capacitor bank charged to 80 kv, the coil current rises to 800 ka in 1.25 μsec producing a magnetic field of about 60 000 gauss in the central region of the coil. Neutrons from the D-D reaction occur in symmetrical bursts centered on the instant of the second and third magnetic field compressions. The maximum neutron emission is 2×10^7 per pulse. Observations to be reported on are: the dependence of neutron yield on pressure and contaminants; time occurrence of neutrons, x-rays, and other radiation; the shape and position of the neutron source; the neutron energy spectrum for both signs of the applied voltage; the magnetic field configuration at maximum compression; the results of high speed photography; and spectroscopic and radiation studies.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Elmore, Little, and Quinn, Phys. Rev. Letters **1**, 32 (1958).

N3. Electromagnetic Wave Surface in a Magnetized Plasma.* WILLIAM P. ALLIS, *MIT.*—The phase velocity of an electromagnetic wave traveling in an arbitrary direction in a cold plasma has been derived before (Astrom, 1950) but the wave surface does not seem to have been exhibited. We shall do so for all significant ratios of wave frequency, plasma frequency, and cyclotron frequency. The surface may have one or two nonintersecting sheets and may have conical points at the origin, but there is no conical refraction. An attempt will be made to correlate the directions of anomalous propagation with the noise emitted from a plasma.

* This work was supported in part by the U. S. Atomic Energy Commission.

N4. Plasma Resistivity and Hall Effect. M. SAKUNTALA, *University of Oklahoma* (introduced by R. G. Fowler).—When a shock wave of highly ionized gas passes a constant magnetic field normal to the wave, an emf is produced in the gas which can be picked up by two probes in the wall of the tube facing one another. The potential difference between the probes is measured with an oscillograph as well as the Hall potential

difference when an external resistance is connected to the probes. It is found that the conventional plasma resistivity is not the appropriate quantity to use in computing the current to these types of probes. The plasma resistivity obtained here corresponds to the positive ion mobility and the flow of charges to the probes is such that the net space charge is always zero.

N5. Dependence of Shock Velocity on Boundary Conditions in a Plasma Driven Shock Tube. G. W. PAXTON AND R. G. FOWLER, *University of Oklahoma.*—Attempts were made to determine the relation between the shock velocity and the electrical energy delivered to the tube. Experiments were conducted in an attempt to determine the relative importance of energy losses to such mechanisms as ionization, viscous losses to the walls, and radiation. Data were obtained using seven different gases, both molecular and atomic, and several different tube sizes. A variety of energies and rates of energy delivery were used with initial gas pressures ranging from 0.5 mm Hg to 100 mm Hg. It is concluded that on an average 20% of the energy delivered to the tube appears as flow motion.

N6. Operational Time and Uniqueness in Theoretical Physics. MOODY L. COFFMAN, *Abilene Christian College.*—Operational definitions of the second do not allow one to say that time is Cartesian in nature, since there is no direct way to compare two seconds measured at the same place at two distinct times. Thus, the Cartesian nature of time must be a basic assumption in theoretical physics. If one is to speak of cosmology, this basic assumption must be kept in mind. To show this, a time which is a nonlinear function of an assumed Cartesian time is derived. It is shown that this new time is experimentally indistinguishable from Cartesian time even if one has arbitrarily large, but finite, precision. Yet this new time gives rise to a vastly different cosmology than Cartesian time. For example, an arbitrary time can be given for the age of the universe. This means that age calculations must be based on an assumed Cartesian time, or a proof that Cartesian time is unique must be given. The demonstration of an alternative time shows that the uniqueness proof cannot be expected. Thus, Cartesian time must be considered an assumption.

N7. Application Of Anomalous Equation To Protons. R. E. BUDWINE AND M. EISNER, *Texas A and M College.*—In a recent article Ulehla[1] has shown that a number of the observed characteristics of the μ meson can be accounted for by assuming that the μ meson satisfies an anomalous Dirac equation. These ideas are applied to the proton and some properties of the anomalous proton discussed. The possibility of identifying this particle with the "heavy proton" of Goldhaber[2] is considered.

[1] I. Ulehla, Nuovo cimento 9, 679 (1958).
[2] M. Goldhaber, Phys. Rev. Letters 1, 467 (1958).

N8. Low-Energy Limit of the Photonuclear Pseudodeuteron Effect. M. DANOS, *National Bureau of Standards.*—The low-energy cutoff of Levinger's pseudo-deuteron effect can be estimated from the radial extent of the two-body correlation in the nucleus. We assume that this correlation is destroyed after one interparticle distance and that the wave function can be approximated by the free two-body wave function for shorter distances. Since the main contribution to the transition matrix element at high energies comes from regions close to the origin, the cross section at high energies will remain unchanged from Levinger's value. At low energies the more distant parts contribute and Levinger's cross section will be quenched. The energy at which this quenching becomes important depends on the density at the location of the nucleon pair in question. In heavy nuclei the effective low-energy cutoff is higher than in light nuclei (over 100 Mev *vs* 60 Mev) since in light nuclei relatively more nucleons are in the surface region with its relatively larger interparticle distances. Thus the pseudodeuteron effect contributes a larger fraction to the integrated cross section in light nuclei than in heavy. In heavy nuclei the observable pseudodeuteron effect is further reduced by the reabsorption of the emitted particles.

N9. Quantum Statistics in a Noncommuting Phase Space. JOHN ROBERT SHEWELL, *Newcomb College.*—The formal correspondence between quantum statistical mechanics and classical statistical mechanics, the former being expressed in terms of matrices, is well known. Several attempts have been made to express quantum statistical mechanics in a classical (commuting) phase space, but the resulting expressions are cumbersome and bear little resemblance to the classical theory. It is shown that if a noncommuting phase space ($\mathbf{pq}-\mathbf{qp} = -i\hbar$, neither $\mathbf{p}$ nor $\mathbf{q}$ being matrices) is used, the expressions are simpler. The formal correspondence with classical statistical mechanics is even closer than is the case with the matrix formulation. Additionally, this offers an entirely new method for solving problems, since only the Hamiltonian operator is needed, and no artificially terminated orthogonal function expansions are used.

N10. Calculation of Atomic and Molecular Integrals. JAMES MILLER, *Esso Research and Engineering Company,* JOHN M. GERHAUSER, *Bendix Aviation,* AND F. A. MATSEN, *The University of Texas.*—General formulas for calculating all one and two center overlap, nuclear attraction, electron repulsion, kinetic energy, and dipole moment integrals will be presented. A systematic scheme for designating these integrals, useful in developing the formulas, will be discussed. The formulas are given in terms of the Kotani A, B, G, and W auxiliary functions. Evaluation of these functions for any argument from tables[1] will be described.

[1] Miller, Gerhauser, and Matsen, *Quantum Chemistry Integrals and Tables* (University of Texas Press, Austin, 1959).

N11. Analysis of Organic Compounds by Deuteron Activation.* DONALD O. NELLIS AND EMMETT L. HUDSPETH, *The University of Texas.*—Various compounds which contain carbon, nitrogen, and oxygen have been activated by deuteron bombardment. The activities of the products N^{13}, O^{15}, and F^{17} have been quantitatively compared with activities induced in a known standard (dimethylglyoxime: $C_4H_8N_2O_2$). The "unknown" samples were rotated (to reduce localized heating) and bombarded in vacuum at 2.5 Mev for 20 sec, and the induced activities were followed for 10 min or more. A pulse-height analyzer was adjusted to pass only the 0.51-Mev annihilation peak; output pulses were fed into a rate meter and Brown recorder. The sum of the decay rates of the three positron emitters was thus known as a function of time following bombardment. Samples bombarded included ammonium nitrate, urea, ammonium benzoate, oxalic acid, and ammonium tartrate. Atomic ratios were in each case correctly predicted from analysis of the delayed activity record. Limitations of the present technique will be discussed.

* Assisted by the U. S. Atomic Energy Commission.

N12. Some Rules Concerning Isotopes. N. EFREMOV, *1061 Intervale Avenue, New York, 59.*—Mattauch's rules[1] (isobar rule, etc.) established on a statistical basis must be broadened. As a first step in this direction we introduce the "mass differences rules of isotopes." In relation to the chief isotopes of the elements of the inert-gas periods these rules

will read: (a) The mass difference magnitudes between the atomic weights of the chief isotopes of successive series of natural elements (e.g., H, He, Li, etc.) cannot be more than 7 or less than −1. (b) The mass difference numbers cannot be composite numbers, but primes (positive integers) such as 2, 3, 5, 7, and also +1 and −1. The numbers 1, 5, and 3 are the prevailing mass difference numbers. (c) The algebraic sums ($S_{m.d.}$) of the mass difference numbers between the chief isotopes of elements of He-, Ne-, Ar-, Kr-, and other inert gas periods are a constant number equal to 15, e.g.,

			A period						
Elements	A	K	Ca	Sc	Ti	V	Cr		Mn
Chief isotopes:	40	39	40	45	48	51	52		55
Mass differences:		−1	+1	+5	+3	+3	+1	+3	

$S_{m.d.} = (-1+1+5+3+3+1+3) = 15.$

[1] J. Mattauch, Z. Physik **91**, 361 (1934); Naturwissenschaften **25**, 738 (1937).

Saturday Afternoon at 1:30

Physics Building, 201

(W. W. Buechner presiding)

Scattering of Nucleons and Nuclei

P1. Inelastic Scattering of Fast Neutrons by Time of Flight.* Pablo L. Okhuysen, J. T. Prud'homme, and Ira L. Morgan, *Texas Nuclear Corporation.*—The angular distributions of the neutrons in the approximate energy region 0.7 to 2.5 Mev resulting from the inelastic scattering of *d-d* neutrons from yttrium, zirconium, iron, and lead have been measured for incident neutrons in the energy region from 3.7 to 4.7 Mev. The angular distributions of the neutrons from 0.5 to 4.0 Mev because of bombardment of the foregoing elements with 15.2-Mev neutrons also have been measured. The measurements were made using a pulsed beam time-of-flight spectrometer of the Los Alamos[1] design. The angular distributions for incident neutrons in the region from 3.7 to 4.7-Mev are isotropic within experimental error (about ±20%). At 15.2 Mev the distributions show slight peaking (20% to 30%) in the forward and back angles for the four elements studied.

* This work was supported by the Modern Physics Research Branch, Aeronautical Research Laboratory, Wright Air Development Center.
[1] L. Cranberg and J. S. Levin, Phys. Rev. **103**, 343 (1956).

P2. Inelastic Neutron Scattering in Y, Zr, Fe, and Pb.* Ira L. Morgan and J. T. Prud'homme, *Texas Nuclear Corporation.*—A ring-type geometry and a single crystal NaI(Tl) spectrometer have been used to determine cross sections for production of gamma rays due to inelastic neutron scattering in Y, Zr, Fe, and Pb in the region from 3.5 to 4.8 Mev. Gamma rays from Y have been found at 0.910±0.01, 1.49±0.01, 1.73±0.01, 2.84±0.02, 3.09±0.02, and 3.48±0.02.

* This work was supported by the Modern Physics Research Branch, Aeronautical Research Laboratory, Wright Air Development Center.

P3. Neutron Inelastic Scattering in N^{14}.* H. E. Hall and T. W. Bonner, *The Rice Institute.*—Gamma radiations from the interactions of fast neutrons with N^{14} have been investigated using *d-d* neutrons. The gamma radiation was produced in a Be_3N_2 annular ring-type scatterer and was observed with a NaI-crystal spectrometer. For neutrons having energies between 5.0 and 7.5 Mev, gamma radiations having energies of 5.1, 4.4, 2.3, 2.1, and 1.6 Mev have been observed. Measurements of the absolute cross section and the variation in the cross section for the production of these gamma radiations have been made over this range of neutron energies.

* Supported in part by U. S. Atomic Energy Commission.

P4. Inelastic Scattering of Neutrons from V^{51}. Harold D. Southward and Emmett L. Hudspeth, *The University of Texas.*—The cross section for excitation of the first excited (320 kev) state in V^{51} by inelastic scattering of neutrons has been measured from threshold up to 932 kev (approximate position of second excited state). Neutrons bombarded a 2-i.d.×4-in. o.d. hollow ring of Plexiglas, ¾ in. thick, which contained vanadium powder. A sodium iodide crystal, shielded from the direct neutron beam by a lead cone, was used to detect the 320-kev radiation. The fraction of this radiation which entered the crystal and produced a count in the photopeak position was determined absolutely by mixing a known quantity of Cr^{51} (which yields the V^{51} γ ray in one branch of its decay process) with the vanadium. A dummy of solid Plexiglas was used to determine the background count produced by neutrons scattered into the crystal detector. Resonances were observed in the excitation curve for neutron energies of 450, 600, 680, and 830 kev with a resolution of about 25 kev. The cross section averages about 0.25 barn for neutron energies between 450 and 750 kev. The experimental results agree very well with Hauser-Feshbach theory for $V_0 = 42$ Mev, $\zeta = 0.2$, $R = 1.45 \times A^{\frac{1}{3}}$ fermis, and a transition $\frac{5}{2}^-$ to $\frac{7}{2}^-$.

P5. Gamma Rays from the Inelastic Scattering of 2.5-Mev Neutrons from Cs^{133}.* Bill L. Lamb and Bruce P. Foster, *North Texas State College.*—The gamma rays from excited states of Cs^{133} were investigated by the inelastic scattering of 2.5 Mev *d-d* neutrons. The CsI(Tl) crystal of the scintillation spectrometer served both as scatterer and as detector, with a NaI(Tl) crystal used for comparison. In the energy range from 0.1 to 0.51 Mev which is covered by this experiment, gamma rays of 0.175 and 0.28 Mev are definitely observed, and the presence of 0.30- and 0.38-Mev rays is probable. The results are in agreement with the results of other investigators.

* Assisted in part by a North Texas State College Faculty Research Grant and a grant by Research Corporation.

P6. Elastic Scattering of Fast Neutrons from C, Fe, Y, Zr, and Pb.* J. T. Prud'homme, Pablo L. Okhuysen, and Ira L. Morgan, *Texas Nuclear Corporation.*—The angular distributions of the neutrons elastically scattered from C, Fe, Y, Zr, and Pb have been measured at various energies in the range from 3.5 to 5.0 Mev. The elastic scattering from carbon has also been obtained at 7.5 Mev. Measurements were made in 10° intervals from 30° to 140° with an angular resolution of ±9°. Detection of the elastically scattered neutrons was accomplished using a time-of-flight technique[1] which insured complete gamma-ray discrimination and very good discrimination against inelastic neutrons. In general, the angular distributions show pronounced peaking in the forward direction accompanied by smaller secondary maxima and minima.

* This work was supported by the Modern Physics Research Branch, Aeronautical Research Laboratory, Wright Air Development Center.
[1] L. Cranberg and J. S. Levin, Phys. Rev. **103**, 343 (1956).

P7. (Abstract withdrawn.)

P8. Alpha-Alpha Scattering in the Range 4.5 to 9 Mev.* C. M. JONES, P. D. MILLER,† AND G. C. PHILLIPS, *The Rice Institute.*—The scattering of alpha particles from He gas has been investigated in the energy range 4.5 to 9 Mev using a differentially pumped, large volume scattering chamber and the rather weak (about 0.01 μa) He^{++} beam from The Rice Institute 5.5-Mev Van de Graaff accelerator. Excitation curves were obtained at c.m. angles of 30° 33′, 54° 44′, and 70° 7′. Because of the poor statistics the cross sections are accurate to only about 5%. Phase shifts have been extracted; only *S* and *D* waves need to be considered to fit all the data to 5%. Between 4.5 and 9 Mev, the *S*-wave phase shift was found to diminish from 103° to about 55°, while the *D*-wave phase shift increases from a value of 18° at 4.5 Mev to about 115° at 8 Mev and then becomes relatively constant. The *S*-wave phases are accurate to about 5° while the *D*-wave phases are accurate to about 10°. Only the well-known *D* state at about 2.9 Mev excitation in Be^8 was observed in these measurements; there is no evidence from alpha-alpha scattering for any other states in Be^8 in this energy region. The level parameters of the *D* state will be discussed and the present results will be correlated with the other alpha-alpha scattering data at other energies.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at the Oak Ridge National Laboratory.

P9. Spin Polarization Determination by Elastic Scattering of Protons and He^3.* P. D. MILLER† AND G. C. PHILLIPS, *The Rice Institute.*—Accurate determination of the phase shifts of elastic scattering for the reactions $C^{12}(p,p)C^{12}$ 1.5 to 4.9 Mev, $He^4(p,p)He^4$ 0.5 to 18 Mev, and $He^4(He^3,He^3)He^4$ 1.0 to 5 Mev allow the calculation of the spin polarization of the elastically scattered particles. Contour maps of spin polarization *versus* energy and scattering angle will be presented and the techniques for performing the calculations will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Oak Ridge National Laboratory.

P10. Elastic Scattering of 6.5- and 8.3-Mev Protons by T and He^3.* L. STEWART, J. E. BROLLEY, JR., AND L. ROSEN, *Los Alamos Laboratory.*—Differential cross sections have been obtained for the elastic scattering of 6.5- and 8.3-Mev protons by T and He^3. The Los Alamos variable-energy cyclotron was the source of protons. Reaction products were recorded in a multiplate camera at angular intervals of 2.5° and with an angular resolution of 0.6°. The 6.5- and 8.3-Mev data are similar. At 8.3 Mev, the angular dependence of the p-T differential c.m. cross sections in mb/sterad may be deduced from the following: 26.6°, 343; 46.1°, 240; 71.0°, 104; 109.6°, 12.8; 132.7°, 36.2; 160.0°, 102. The corresponding cross sections for p-He^3 are 263, 217, 109, 26.3, 58.4, and 160, respectively. The standard deviation at all angles is approximately 3.5%. Part of the difference between p-T and p-He^3 scattering can be attributed to the Coulomb interaction and the competing $T(p,d)D$ reaction. The 8.3-Mev p-T elastic scattering data do not agree with recent n-He^3 results at a comparable energy even if one permits the maximum phase difference between the Coulomb and nuclear scattering amplitudes. At the lower energy, however, there is remarkable agreement between the p-T measurements and recent n-He^3 elastic scattering data at 6.0 Mev.

* Work done under the auspices of the U. S. Atomic Energy Commission.

P11. Elastic Scattering of Deuterons by Tritium and by Helium-3.* A. H. ARMSTRONG, J. E. BROLLEY, JR., AND L. ROSEN, *Los Alamos Scientific Laboratory.*—The method described in the previous abstract was used to measure differential cross sections at 5, 6, 8, 10, 12, and 14 Mev for D-T and D-He^3 elastic scattering. The major features of the data are strong forward-backward scattering at all energies, with two minima at approximately 65° and 130° and a maximum between 90° and 100°. The high intensities in the backward direction are attributed to inverse stripping reactions. The D-T and D-He^3 cross sections are similar in shape at all energies and are also identical in magnitude at energies above 8 Mev except in the angular region where Coulomb scattering is important. Representative values of the c.m. cross sections in mb/sterad are given in Table I.

TABLE I.

E / θ	5 Mev (prelim)		8 Mev		12 Mev		14 Mev	
	T	He^3	T	He^3	T	He^3	T	He^3
~17°	520	1036	844	947	785	858	782	795
~65°	42.5	42.0	28.6	27.3	18.7	19.1	20.8	20.1
~90°	73.0	56.2	98.7	91.6	65.6	67.2	58.4	59.9
~130°	84.9		38.9	32.9	22.0	18.9	21.8	18.6
~160°	573	629	307	344	137	137	105	98.6

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Physics Building, 203

(F. A. MATSEN presiding)

Invited Paper

Q1. X-Ray Absorption Edge Studies on Magnetic Materials. H. P. HANSON, *University of Texas.* (30 min.)

X-Ray and Optical Spectroscopy

Q2. Correlation Effects in the X-Ray Scattering Factors for Two-Electron Ions.* J. N. SILVERMAN, O. PLATAS, R. D. MCIVER, AND F. A. MATSEN, *The University of Texas.*—The coefficients and optimum orbital exponents in the Slater atomic wave function $C_1(1s1s')+C_2(2p^2)$ have been determined by the variation principle for the ions H^- to C^{++++}. From these functions, x-ray scattering factors have been calculated for a wide range of $\sin\theta/\lambda$. It has been shown[1] that the scattering factors for H^- based on the wave function $(1s1s')$, in which there is some radial correlation, are considerably different than those previously calculated from functions in which there is no correlation. The scattering curve for H^- derived from the present calculation, in which angular correlation is added to the radial correlation, is intermediate to the noncorrelated and radially correlated curves at low values of $\sin\theta/\lambda$ and lies slightly below the radially correlated curve at higher values of $\sin\theta/\lambda$. It would appear that correlation effects in the hydride ion can be detected experimentally by a low-temperature x-ray investigation of an alkali metal hydride, provided the ions are not strongly distorted by the crystal field.

* This research was supported by the Robert A. Welch Foundation of Houston, Texas, and the Office of Ordnance Research, U. S. Army.
[1] Hurst, Miller, and Matsen, Acta Cryst. **11**, 320 (1958).

Q3. Excitation Cross-Section Measurements on Helium 3^1P Level by Optical Methods.* ROBERT M. ST. JOHN, R. G. FOWLER, AND C. G. BRONCO, *University of Oklahoma.*—Absolute measurements on cross sections for excitation of the helium atom from ground to the 3^1P level by electron impact have been made. Observations were made on 5016-A radiation using a high gain photomultiplier. The photomultiplier current was measured with a microammeter for moderate light intensity levels, but with single pulse counting techniques at low levels. The light intensity from the collision chamber was measured as a function of electron beam current and helium pressure. The intensity was proportional to the current. This showed multiple collisions by a single electron were not prevalent. The intensity was proportional to pressure for pressures up to about 7×10^{-3} mm Hg. Above this pressure the intensity rose more rapidly, indicating that resonance radiation effects were in operation. Relative intensity data by Fowler and Duffendack[1] have been used to extend the intensity-pressure curve to pressures as high as 0.1 mm Hg. Last, the excitation function of the 3^1P level was found with helium pressures low enough to prevent resonance radiation effects. The maximum cross section occurred for electrons of about 65- or 70-ev energy.

* This work supported by the U. S. Air Force Office of Scientific Research.
[1] R. G. Fowler and O. S. Duffendack, Phys. Rev. **76**, 81 (1949).

Q4. Infrared Dispersion of Some Organic Liquids. R. E. KAGARISE, *U. S. Naval Research Laboratory.*—The dispersions of carbon tetrachloride, tetrachloroethylene, methylene iodide, and acetone in the 2- to 15-μ wavelength region have been measured using the interferometric method previously described.[1] The problem of assigning the proper orders of interference to the observed fringe system has been solved by studying the compounds of interest dissolved in carbon disulfide. Since the orders of interference are reliably known for CS_2, one can follow the shift in order as the concentration of the solute is increased in a step-wise fashion from 0 to 100%. From the observed dispersion curves it is possible to compute a number of other molecular properties including integrated absorption coefficients. This has been done for the 13-μ doublet band of carbon tetrachloride and the 9-μ band of methylene iodide. The calculated and observed values are in good agreement.

[1] R. E. Kagarise and J. W. Mayfield, J. Opt. Soc. Am. **48**, 430 (1958).

Q5. Electronic Structure of Lithium Hydride. VI. Radially Correlated Functions.* J. M. ROBINSON, J. D. STUART, AND F. A. MATSEN, *Texas A and I College, and The University of Texas.*—The electronic energy of LiH has been calculated with wave functions $(1s1s'2s,h')$, $(1s1s'2p_0h')$, and $(1s1s',h''h''')$. The letters signify Slater-type atomic orbitals and primes different orbital exponents. For atoms the use of different orbital exponents for the same atomic orbital has been shown to introduce some radial correlation and to yield energies better than the single configuration Hartree-Fock functions. The energy of LiH as calculated from the radially correlated functions is -217.72 ev, 0.76 volt lower than from the corresponding uncorrelated functions. An interesting feature of the calculation is the fact that while the energy of the hydride ion calculated from (hh') is 1.10 ev lower than from $(h''h'')$, there is almost no effect on the LiH energy in changing from $(1s1s',h'h')$ to $(1s1s',h''h''')$. The change decreases the corresponding diagonal element but at the same time increases the size of the nonorthogonality integral with $(1s1s'2s,h)$, the most important structure. It appears from the foregoing that the change reduces the effectiveness of the ionic structure in the variation calculation by causing it to resemble more closely the covalent structure.

* This research is supported by the Robert A. Welch Foundation of Houston, Texas, and the Office of Ordnance Research, U. S. Army.

Q6. A Double Minimum Potential Function.* N. W. NAUGLE, J. R. HENDERSON, AND J. B. COON. *A and M College of Texas.*—Recent literature[1] suggests that frequently an excited electronic state of a molecule has a potential function with a double minimum in one of the antisymmetrical normal coordinates. Such a potential function may be described approximately by $V=(1/2)\lambda Q^2+A\exp[-(e^4\lambda/2A)Q^2]$. The coefficient of the exponent is determined by requiring that the two minima be parabolic. Using machine calculations the low-energy levels and the corresponding wave functions of this potential have been obtained in a dimensionless form applicable to any double minimum problem. A linear combination of the first twelve harmonic oscillator wave functions corresponding to the potential $\frac{1}{2}\lambda Q^2$ is used as a variation function. This approach is appropriate for low potential barriers. The secular determinant is solved by the Jacobi method. As an example, the barrier height in the out-of-plane bending coordinate of the $^1A_2$ state of formaldehyde, as determined from the observed levels, is 550 cm^{-1} for H_2CO and 490 cm^{-1} for D_2CO. The wave functions will permit calculation of band intensities.

* Supported by the Air Force Office of Scientific Research.
[1] H_2CO, J. C. D. Brand, J. Chem. Soc., 869 (1956); ClO_2, J. B. Coon, J. Mol. Spectroscopy **1**, 93 (1957); SO_2, W. S. Mulliken, Can. J. Chem. **36**, 22 (1958); C_2H_4, P. G. Wilkinson, J. Mol. Spectroscopy **2**, 395 (1958).

Q7. Vibrational Spectra of 1, 1, 2, 2-Tetrafluorethane.* PETER KLABOE AND J. RUD NIELSEN, *University of Oklahoma.*—The infrared absorption spectrum of gaseous CF_2H-CF_2H from 300 to 5000 cm^{-1} has been studied at 5 temperatures between 30 and 180°C. The infrared spectrum of the crystalline phase at -180°C was recorded. The Raman spectrum of the liquid was obtained at 4 temperatures between 30 and -85°C, and polarization measurements were made. The large number of strong bands indicates the presence of more than one rotational isomer. One of these is evidently the *trans*-form of symmetry C_{2h}. In addition, there appear to be two enantiomorphic *gauche*-forms. The bands assigned to the latter are absent in the infrared spectrum of the crystalline solid. The variation with temperature of the intensities of the infrared bands of the gas shows that the *trans*isomer is the most stable. Preliminary measurements give $\Delta H_0^\circ=800$

cal/mole. In the liquid phase the enthalpy difference is much smaller. Practically all the fundamental vibrational frequencies have been assigned, and the spectra have been interpreted in detail.

* Supported in part by the U. S. Atomic Energy Commission.

Q8. Theoretical Treatment of Discrete Spectra and the Ionization Potential of F_2. KATSUNORI HIJIKATA, *University of Oklahoma.*—It has been shown that all the lower excited states of the F_2 molecule converging to $F(GS)+F(GS)$ at the infinite separation are not stable.* The discrete emission spectra ($^1\Sigma-{}^1\pi$) reported by Gale and Monk,[1] therefore, must be the transition between the upper states which converge to ionic structures $F^+(^1D)+F^-(^1S)$, and/or to excited structures $F(GS)+F[(2s)^2(2p)^4(ns)$ or $(np)]$. For the higher states of F_2 in which the ionic structure is predominant the calculation reported previously* was refined by taking the effective nuclear charge 2.53 for $2s$ and $2p$. This value was determined by minimizing the total energy of the separated atomic constituents. To find the possibilities of transitions to or from the excited states related to the excited atomic structures, the energy of the ground state ($^3\pi_g$) of the F_2^+ was calculated by using the effective nuclear charge 2.62 determined as above, and the approximate positions of the Rydberg levels were predicted. The calculation is based on ASMO with CI, and shows that the transition measured by Gale and Monk is probably $^1\Sigma_u^+$ (ionic) $-{}^1\pi_g$ (excited). The ionization potential of F_2 is also discussed.

* Oklahoma Meeting (March, 1957).
[1] Gale and Monk, Astrophys. J. 69, 77 (1929).

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Griffin, J. J.—G9
Grosskreutz, J. C.—B4
Haenni, H.—C10, G3
Hall, H. E.—P3
Hall, W. S.—C1
Hampton, L. D.—B3
Hanson, H. P.—Q1
Hatcher, C. R.—L4, L5
Henderson, J. D.—C8
Henderson, J. R.—Q6
Hijikata, Katsunori—Q8
Hill, O. H.—B7
Horton, C. W.—B3
Hubbert, M. King—F2
Hudson, O. M., Jr.—G2
Hudspeth, Emmett L.—C8, N11, P4
Huffman, D. R.—B1, B8
Hughes, D. S.—F3
Johnson, J. H.—G4
Jones, C. M.—P8
Kagarise, R. E.—Q4
Kashy, E.—C7
Kerr, E. C.—J1
Kinsey, B. B.—E2
Klaboe, Peter—Q7
Laing, R. A.—B11
Lamb, Bill L.—P5
Larson, H. V.—L8
Levinger, J. S.—K3
Little, E. M.—N2
Little, P. F.—N1
Loeb, L. B.—A2
Martin, J. S.—L12
Marton, L.—F1
Mather, Robert L.—L3
Matsen, F. A.—N10, Q2, Q5
McIver, R. D.—Q2
Miller, James—N10
Miller, P. D.—P8, P9
Millett, W. E.—L4, L5
Morgan, Ira L.—G2, P1, P2, P6
Morgan, L. O.—L10
Mukerji, Ambuj—G5, L1
Myers, I. T.—L8
Naugle, N. W.—Q6
Nellis, Donald O.—N11
Nelson, J. W.—C8
Nielsen, J. Rud—Q7
Nolle, A. W.—L10
Norwood, M. H.—B1
Okhuysen, Pablo L.—P1, P6
Oliphint, Clark—B2
Paxton, G. W.—N5
Peoples, Joseph T.—L7
Perry, R. R.—C7
Phillips, G. C.—C4, C9, K2, P8, P9
Platas, O.—Q2
Prud'homme, J. T.—P1, P2, P6
Quinn, W. E.—N2
Rabson, T.—C10
Rao, D. A. A. S. N.—C9
Rester, D. H.—G6, G7
Retz-Schmidt, T.—C2, C5, G3
Risser, J. R.—C7
Robinson, J. M.—Q5
Rorschach, H. E., Jr.—B11, J3
Rosen, L.—P10, P11
Sakuntala, M.—N4
Salaita, G. N.—G5, L1
Sandlin, B. J.—B10
Shewell, John Robert—N9
Silverman, J. N.—Q2
Smith, George W.—L9
Southward, Harold D.—P4
Spencer, R. R.—C4, C9
Squire, C. F.—J4
Starner, J. W.—L2
Stewart, L.—P10
St. John, Robert M.—Q3
Stuart, J. D.—Q5
Taylor, H. L.—B8
Thompson, James C.—B5, B9, B10
Tobocman, W.—K4
Vallarta, Manuel Sandoval—E1
Von Engel, A.—A1
Watson, Robert B.—B5
Wegner, H. E.—C1
Williamson, Claude F.—L7
Wittenborn, A. F.—B7
Yarnell, J. L.—J2
Young, T. E.—C9

Preliminary Announcement of the 1959 Spring Meeting at Washington

There is a surprise in the year's announcement of the Spring meeting. There is nothing novel about the city (Washington), nor the dates, which are Thursday, Friday, and Saturday, April 30, May 1, and 2. The scientific sessions, however, will be held in the Willard and Raleigh hotels, in the Departmental Auditorium, and in the Department of Commerce Auditorium, all in downtown Washington. This may be good news to some and not so good to others, but let judgment be suspended until we see how it works out.

This innovation—or rather, return to the practices of years ago—is compelled by our fidelity to our traditional dates, those that follow immediately upon the meeting of the National Academy of Sciences. Alas, this is the very time of year when Washington is most popular, and conventions larger and more opulent than ours are competing with ours for space. Our Local Committee is doing its best to stabilize our arrangements for the future, and its best is something that few can rival and no one can surpass.

Room reservations are to be made by writing to the Willard Hotel, 14th and Pennsylvania Avenues NW, Washington, D. C. You *must* mention that you are a member of this Society coming to its meeting!! The Willard engages to provide rooms in other hotels after its allotment to our members is fully booked: you may designate the hotels of your choice.

Deadline is Friday, February 20. Abstracts are to be sent to Karl K. Darrow, Secretary, American Physical Society, Columbia University, New York 27, New York. Re-read the instructions for the preparation of abstracts (page 121). After excessively numerous warnings, we now reject abstracts of which only carbons are submitted.

Proceedings of the American Physical Society

Minutes of the Fall Meeting of the New England Section at Williams College, Williamstown, Massachusetts, on October 11, 1958

THE New England Section of the American Physical Society held its annual Fall Meeting on Saturday, October 11, at Williams College, Williamstown, Massachusetts. There were approximately sixty persons who registered. At the Morning session ten contributed papers were given. They were divided into two groups which were given simultaneously. Papers 1, 6, 7, 8, 10 were given at one place while papers 2, 3, 4, 5, 9 were given at the other. The reason for this division was that each contributed paper was allowed up to 20 minutes in order that the person giving the paper have time to develop more of the background of the work. This additional time appears to be well worthwhile in view of the general nature of the audience at these meetings.

After luncheon, the annual business meeting was held. A treasurers report was read and the following council members were elected to serve until the next Fall Meeting:

Chairman	M. A. Jeppesen (Bowdoin)
Vice Chairman	R. F. Kingsbury (Trinity)
Secretary-Treasurer	P. J. Bray (Brown)
Executive Committee	H. H. Hall (New Hampshire)
	G. Holton (Harvard)

Following the business meeting three invited papers were given.

Some Electronic Devices Useful for Teaching. Howard P. Stabler, *Williams College.*

Superfluidity. Leon N. Cooper, *Brown University.*

The Work of the AAPT Committee on Apparatus for Educational Institutions. Dr. William C. Kelly, *American Institute of Physics.*

Robert F. Kingsbury, *Secretary-Treasurer*
New England Section

Contributed Papers

1. Relativistic Mechanics of a Particle. D. A. Park, *Williams College.*—The dynamics of a particle in special relativity can be developed in a form analogous to that of Newtonian mechanics. One starts with the observation that the four-vector generalization of the Newtonian momentum and the Lorentz transformation are two complementary but equivalent means for describing the behavior of a body in motion. This suffices to determine the four-vector unambiguously, and the laws of dynamics are then conveniently expressed by the assertion that this vector satisfies a conservation law.

2. Thermal Wheatstone Bridge. A. E. Benfield, *Harvard University.*—The apparatus to be described, essentially a thermal analog of the electrical Wheatstone Bridge, consists of two rods in parallel, well lagged. The upper ends of both rods are kept at the same temperature, and the lower ends of both are held at another, lower temperature. One rod is a

continuous piece of nickel; the other is a shorter length of nickel in series with a sample of the unknown. Positions of equal temperature in the two nickel rods, are located by fixed copper wires, which serve as thermojunctions. Being a null method, it is not necessary to measure any quantity of heat, or any temperatures or temperature differences with great accuracy, or to compute any heat flow. Furthermore, by making the two sections of the equipment similar, heat leakages tend to cancel. Several specimens of different length are measured for each unknown material in order to remove the effects of the interface temperature drop at the surface of contact between the nickel rod and the unknown sample. Preliminary measurements indicate that it is fairly easy to measure the thermal conductivity of a good conductor, relative to that of nickel, with an accuracy of a few tenths of a percent.

3. Problems of Instrumentation of Exploding Wire Phenomenon. W. G. CHACE AND E. H. CULLINGTON, *Geophysics Research Directorate, Air Force Cambridge Research Center.*—The problems encountered in instrumenting an electrically exploded wire are considered. It is pointed out that the same problems stem mainly from four sources. 1. The submicrosecond duration of the phenomena. 2. Current maxima up to 10^6 amp. 3. Rates of change of current with di/dt 2.5×10^{10}. 4. Dynamic ranges of five orders of magnitude. Actual problems presented by each of these factors will be discussed and solutions suggested. Methods for quantitative plotting of current, voltage and light intensity, against time will be analyzed on the basis of the four limiting factors mentioned. Control and synchronization constitute a problem of equal magnitude in this type of experiment and will be discussed as they effect measurements. Details of some actual apparatus used in the authors' work will be presented briefly.

4. Influence of Temperature on the Transmittance of Glass Filters Used in Meteorology. A. K. ANGSTROM AND A. J. DRUMMOND, *Eppley Laboratory, Inc.*—Filters are now employed regularly in meteorology, especially for separating certain spectral regions in the radiation received from sun and sky and, to a lesser extent, that of longer wavelength characteristic of the terrestrial radiation. In selecting these filters fundamental and also practical applications have to be considered. An important aspect, in both cases, is that the separation between the wavelength bands under study shall be as sharp as possible, in order that the relevant computing work be reduced to a minimum. Hence, the filter types agreed upon for meteorological research are characterized by an almost perfect transmittance above or below specific limiting values of wavelength. The present investigation is concerned with the influence of temperature on the transmittance of these filters and, in particular, the effect in shifting the boundary region between transmission and complete opaqueness. The results, of which a typical selection is contained in the paper, have bearing upon the accuracy in determining the factors influencing the attenuation of solar radiation within the atmosphere. The same is true in regard to the wavelength groups of biological and therapeutic interest.

5. Low-Temperature Specific Heats of Three Plastics.* R. J. NOER,† C. W. DEMPSEY, AND J. E. GORDON, *Amherst College.*—The specific heats of polystyrene, lucite, and teflon have been measured in the temperature range between 1.4° and 4.2°K. The measuring apparatus is similar to that described by Snider and Nicol.[1] The results for lucite and polystyrene are well described by $C=aT^3$ cal/g deg where for polystyrene $a=1.5\times10^{-4}$ cal/g deg^4 and for lucite $a=8.4\times10^{-6}$ cal/g deg^4. The teflon data can be represented approximately by $C=10^{-6}T^3$ cal/g deg.

* This work is part of a thesis submitted by R. J. Noer in partial fulfillment of the requirement for the degree of Bachelor of Arts with honors at Amherst College.
† Presently at the University of California, Berkeley, California.
[1] J. L. Snider and J. Nicol, Phys. Rev. 105, 1242 (1957).

6. Nuclear Spin Saturated by Ultrasonics in Sodium Chloride.* E. F. TAYLOR AND N. BLOEMBERGEN, *Harvard University.*—It has been known for some time that nuclear spin systems in ionic solids can interact with lattice vibrations via the nuclear electric quadrupole moment. This interaction can be used to study the constants which relate lattice distortion to electric field gradient at the nucleus and through these constants the electronic configuration in ionic solids. Until recently an interpretation of quantitative results in this field was hampered by insufficient knowledge about the configuration of the ultrasonic waves. In the present experiment an ultrasonic vibrational mode with rather well-defined properties has been set up in a cylindrical single crystal rod of sodium chloride. The saturation of the spin levels of Na^{23} and Cl^{35} by acoustically induced quadrupole transitions, $\Delta m=\pm2$, has been measured in the steady state by a standard NMR technique. The ratio of the independent components of the fourth-order tensor connecting the electrical field gradient tensor at the nuclei with the strain deformation tensor have been determined. This ratio satisfies the isotropy condition rather than the Cauchy relation predicted from the ionic point charge model of the lattice.

* Supported jointly by the office of Naval Research, Signal Corps, and the Air Force Office of Scientific Research.

7. Cl^{35} Pure Quadrupole Resonances in Nitrogen Mustards.* H. O. HOOPER AND P. J. BRAY, *Brown University.*—Cl^{35} pure quadrupole resonances have been observed in several nitrogen mustards at 77° and 300°K. The compounds investigated are of the type previously studied in conjunction with their property of affecting cancer growth. Several of the nitrogen mustards, when used in the treatment of cancer in animals and human patients, have shown some success in inhibiting cancer growth. W. C. J. Ross[1] has shown that for nitrogen mustards a relationship exists between their activity as tumor growth inhibitors and their chemical rates of hydrolysis. From this tabulation it can be seen that only compounds with a rate of hydrolysis greater than a certain value have any positive activity as tumor growth inhibitors. Since the rate of hydrolysis depends upon the molecular electronic charge at the position in the molecule where hydrolysis occurs, and since the frequency of the pure electrical quadrupole resonance also depends upon the molecular electronic charge distribution, we have attempted to correlate the resonance frequencies obtained for these nitrogen mustards with their activity as tumor growth inhibitors.[2]

* Work supported by a grant from the National Science Foundation.
[1] W. C. J. Ross, "The chemistry of cytotoxic alkylating agents," *Advances in Cancer Research* (Academic Press, Inc., New York, 1953), Vol. 1.
[2] We are indebted to Dr. Richard Bersohn, Department of Chemistry, Cornell University, for suggesting this investigation.

8. Time-Reversal Invariance in Beta Decay. ICKO IBEN, JR., *Williams College.*—By comparing, for specific decay processes, the theoretical and experimental distributions of the decay products in angle and energy, it is possible to gain some information concerning the transformation properties of an interaction Hamiltonian under the operations of charge conjugation, space inversion, and time reversal. The basic procedure is to obtain the distribution function for a process which is assumed to be triggered by the interaction Hamiltonian first written in its most general form (i.e., without assuming invariance under the operations of space inversion, charge conjunction, and time reversal). An experimental

investigation of the dependence of the decay probability on various characteristics of the decay products (e.g., on the relative orientation of their momenta and spins) sets an upper and a lower limit on terms which appear in the general distribution function. The more precisely these limits can be determined, the more definite will be the resulting statement regarding a corresponding invariance property of the Hamiltonian. The distribution function associated with the process—first forbidden, transverse polarized, beta followed by a pure multipole gamma ray—is presented and discussed in connection with the question of time reversal invariance. For the particular case of Au^{198} it is shown that experimental results are consistent with time-reversal invariance but are also consistent with an appreciable violation of this invariance.

9. Study of the So-Called "Anomalous Losses" in 3% Si–Fe Grain-Oriented Strip Material. PETER W. NEURATH, *General Electric Company, Pittsfield, Massachusetts.*—If power frequency losses of magnetic sheet materials are considered to be the sum of hysteresis and eddy current losses, it has been shown repeatedly that they cannot be calculated by classical methods so as to get agreement with experimental data. If the domain structure of the material is taken into account explicitly, however, agreement can be obtained for very special simple cases. Pry and Bean[1] have attempted to extend this approach to a "practical" material such as grain-oriented 3% Si–Fe, assuming a plausible domain structure. As in a practical case order-of-magnitude agreement between theory and experiment is not good enough, it has been attempted to check their prediction by measurements on a number of different samples of this kind. The thickness of the samples was varied in different ways in order to provide another variable. It is shown that the theory does not take account of some important factors. The implications of these results in the search for better materials are discussed.

[1] R. Pry and C. P. Bean, J. Appl. Phys. **29**, 532 (1958).

10. $O^{16}+O^{16}$ at 160 Mev. P. ROLL* AND F. E. STEIGERT, *Yale University.*—A thin target of oxygen has been bombarded with a beam of 160-Mev oxygen ions from the Yale Heavy Ion Linear Accelerator. The reaction products were observed in 50-μ nuclear emulsions of various types, arranged at angles every $2\frac{1}{2}°$ from 5° back to 150°. The various species of light reaction particles may be identified by conventional techniques. Various heavy fragments are also observed. However, not all of these are as yet identified. The elastic scattering peak is easily recognized both by range measurements and by the general appearance of the tracks. The elastic cross section shows very marked departure from Rutherford scattering, beginning in the region of 25° center-of-mass angle. At 40° center-of-mass angle it becomes extremely difficult to differentiate an "elastic" peak from the general reaction fragment. Tentative data will be presented on the range energy relationship of oxygen ions in nuclear emulsions, as well as their general characteristics in the different types of emulsions. In particular, the "taper" length in G5 emulsions appears to be a potential means of heavy ion identification.

* G. E. Rice fellow. This work was supported in part by both the Office of Naval Research and the Atomic Energy Commission.

MINUTES OF THE ELEVENTH ANNUAL GASEOUS ELECTRONICS CONFERENCE HELD AT NEW YORK CITY, ON OCTOBER 22, 23, 24, AND 25, 1958

THE Eleventh Annual Gaseous Electronics Conference was held at the Barbizon-Plaza Hotel in New York City on October 22, 23, 24, and 25, 1958. The Conference was jointly sponsored by the Division of Electron Physics and the Bell Telephone Laboratories, Inc. Sessions on Thursday, October 23, were held at Bell Telephone Laboratories, Murray Hill, New Jersey. This was by far the largest of the series of such annual conferences to date; there were 441 registrants, 5 invited papers, and 57 contributed papers. This circumstance arose from the interest in the recently declassified fusion physics and technology, with which topics the invited papers dealt. Titles of the invited papers and abstracts of most of the contributed papers are printed below.

The Conference banquet was held on Thursday evening, October 23. Dr. J. B. Johnson, head of the Physics Department, Thomas A. Edison Laboratories, McGraw-Edison Company, was the after-dinner speaker. He presented a talk "Edison's Contributions to Thermionics."

The Conference Committee for the coming year consists of W. P. Allis (Chairman), L. M. Branscomb (Secretary), D. E. Kerr, W. B. Kunkel, and D. J. Rose.

D. J. ROSE, *Secretary*
1958 Gaseous Electronics Conference

WEDNESDAY MORNING AT 9:30

(B. BEDERSON, chairman)

Cross Sections

A1. Low-Energy Collision Cross Sections for D^+ Ions in Deuterium.* W. H. CRAMER, *University of Florida.*—The apparatus and experimental techniques previously employed in studies of the interactions of inert gas ions in the inert gases[1,2] have been used for measurement of elastic and charge-exchange cross sections of D^+ ions in deuterium in the energy range from 4 to 400 ev. Charge exchange was observed only at energies of 80 ev and higher. The elastic cross sections are qualitatively similar to those of Simons and co-workers[3] for H^+ ions in hydrogen; however these authors did not detect

any charge exchange up to energies of 135 ev. Constants for empirical potential energy functions for the interaction of D^+ and deuterium have been evaluated.

* Supported by a grant from the National Science Foundation.
[1] W. H. Cramer and J. H. Simons, J. Chem. Phys. **26**, 1272 (1957).
[2] W. H. Cramer, J. Chem. Phys. **28**, 688 (1958).
[3] Simons, Fontana, Muschlitz, and Jackson, J. Chem. Phys. **11**, 307 (1943).

A3. Optical Excitation Cross-Section Measurements of Helium 3^1P Level.* R. M. St. John, C. G. Bronco, and R. G. Fowler, *University of Oklahoma.*—Absolute measurements on cross sections for excitation of atoms by electrons are being made. The helium 3^1P level is being studied by observing 5016-A light from the collision chamber. Low gas pressures and small electron beam currents require the use of single-pulse counting techniques in which a high-gain photomultiplier, linear amplifier, and scaler are used. The photomultiplier is employed at liquid air temperatures to reduce dark counts. The apparent cross section for the helium 3^1P level was found to be independent of electron beam current. It showed a broad maximum whose peak occurred at an electron energy of about 120 ev. The cross section appeared to be independent of pressure for pressures as high as 10^{-3} mm Hg. Thus, secondary processes presumably were not taking place. Absolute values of the excitation cross section of the 3^1P level will be obtained when calibration of the light-measuring equipment is completed. Estimates place the peak value near 10^{-18} cm^2.

* Work supported by the U. S. Air Force Office of Scientific Research.

A4. Study of Inelastic Collisions of Electrons in Molecular Gases Using the Trapped-Electron Method.* G. J. Schulz, *Westinghouse Research Laboratories.*—The energy loss processes in N_2, H_2, O_2 were studied using electron beam techniques. Those electrons which have undergone an inelastic collision, and therefore lost a portion of their initial energy, are trapped in a potential well which prevents their escape to the electron beam collector. These "trapped" electrons can reach a cylindrical collector surrounding the electron beam. The potential well can be varied from 0 to about 1.5 v. We can therefore obtain the cross section for the appearance of electrons of energy up to 1.5 v as a function of the energy of the electron beam. For the simple case of helium, the method measures the excitation cross section up to energies 1.5 ev above threshold, and the results are in good agreement with previous experiments. The excitation functions for electronic transitions in H_2, O_2, N_2 were obtained. An anomalous energy-loss process in N_2, with a peak cross section at 2.3 v, was observed, similar to that reported by R. Haas.[1]

* Work supported in part by the Office of Naval Research.
[1] R. Haas, Z. Physik. **148**, 177 (1957).

A5. Ionization of Hydrogen and Oxygen Atoms near Threshold.* Wade L. Fite and R. T. Brackmann, *General Atomic Division of General Dynamics Corporation.*—Using modulated atomic beam techniques, the cross sections for ionization of ground-state hydrogen and oxygen atoms upon electron impact have been measured, in the neighborhood of threshold. For both atoms the cross section appears proportional to the excess incident electron energy, and confirms the prediction of Geltman.[1] For the hydrogen atom the absolute value of the cross-section slope is 0.078 $(\pm 0.006)\pi a_0^2$/ev, while Geltman's S-wave theory predicts $0.044\pi a_0^2$/ev. The discrepancy is understood on the basis of the theory's consideration of only the S-wave contributions to the total cross section.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] S. Geltman, Phys. Rev. **102**, 171 (1956).

A6. Measurement of Total Ionization by Low-Energy Electrons. B. T. McClure, *Bell Telephone Laboratories.*—An earlier investigation[1] of the number of ions n created by an electron which is stopped by collisions with gas molecules in a field-free region has been extended. The effect of electrons reflected to their source and the effect of the loss of high-energy electrons at the wall of the apparatus have been considered quantitatively. The influence of these phenomena is taken into account in the interpretation of the data. The number n has been measured as a function of primary electron energy ranging from the ionization energy up to 200 ev in neon and in neon containing a small admixture of argon. The data obtained are used to extend the Maier-Leibnitz measurement[2] of the total excitation probability in neon up to 43 ev. This probability goes through a broad maximum (about 1 cm^{-1} mm Hg^{-1}) at an electron energy of 27 ev.

[1] B. T. McClure, Bull. Am. Phys. Soc. Ser. II, **3**, 83 (1958).
[2] H. Maier-Leibnitz, Z. Physik. **95**, 499 (1935).

A7. Quantum Effects in Ionic Mobility at Low Temperatures. S. Geltman, *National Bureau of Standards.*—At low relative velocities of impact between ions and gas atoms, the diffusion cross section departs from its classical value. In particular, the Langevin ion-atom potential (hard-sphere repulsion of radius σ, and $-c/r^4$ attraction for $r>\sigma$) gives classical $Q_d \sim (c/m)^{\frac{1}{2}} v^{-1}$ in the low velocity limit, while zero-energy quantum cross section is $4\pi\sigma^2(\gamma \operatorname{ctn}^2\sqrt{\gamma})$, where $\gamma = (2m/n^2)(c/\sigma^2)$. The limiting low-temperature behavior of the mobility is $T^{-\frac{1}{2}}Q_d^{-1}$, which will have Ramsauer-like variations as a function of the potential parameters. It is suggested that quantum effects may help explain some of the anomalously low mobility measurements at low temperatures which were previously ascribed to clustering.

Wednesday Afternoon at 2:00

(L. M. Chanin, chairman)

Sputtering and Arcs

B1. Monte Carlo Sputtering Calculations. R. R. Coveyou, D. T. Goldman, and D. E. Harrison, *Oak Ridge National Laboratory.*—In previous treatments of the sputtering problem both at higher energies and in the medium-low-energy range many of the approximations are quite questionable because their range of validity is highly uncertain. In an effort to resolve some of these difficulties we have turned to Monte Carlo techniques. Using an IBM 704 we have calculated a large number of ion histories, following the birth, progeny, and death of the ion and all of its daughters, assuming that death occurs when a particle no longer has sufficient energy to pass the surface energy barrier. In our preliminary analysis we examined hard-sphere, screened-Coulomb, and pure-Coulomb (suitably cut off) interactions in appropriate energy ranges. Based on this analysis, we used screened-Coulomb interaction in all incident ion collisions, and assumed a hard-sphere interaction for the production of all grandchildren and later generations. These histories were then

analyzed under various assumptions. Assuming that the primaries are produced with a uniform distribution in depth, valid for high energies, we computed the sputtering ratio and also energy and angular distributions for the outgoing particles. Other models will be used at lower energies. We shall present preliminary results of this continuing program.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

B2. Velocities of Sputtered Atoms.* G. WEHNER, *General Mills, Inc.*—The average velocities of atoms sputtered from Ni, Pt, and Au targets by Hg^+ ions of 200- to 1000-ev energy are measured with a method which was used previously for the velocity determination of vacuum evaporated atoms.[1] Sputtered atoms are received by the underside of a pan suspended from a quartz helix in the tube. The deposited atoms exert a force, $\dot{M}\times v_s$, which displaces the pan upward when the target is connected with the negative bombarding voltage. The continuous deposition of sputtered material increases with time the weight of the pan and one can determine the time interval t after which the pan has returned to its original position or the momentum force has been compensated by the weight increase. From $\dot{M}\times v_s=\dot{M}\times t\times g$ follows that v_s can be determined by a simple time measurement without the knowledge of $\dot{M}$ or the constants of the balance. The average velocities turn out to be unexpectedly high, corresponding to energies of between 10 and 20 ev. Curves are given for the velocities as functions of bombarding energy and angle of ejection.

* Partly supported by Office of Naval Research.
[1] Paul and Wessel, Z. Physik. 124, 691 (1948).

B3. Sputtering Yield of Germanium in Rare Gases.* N. LAEGREID AND G. WEHNER, *General Mills, Inc.*—Sputtering yields of germanium bombarded by Xe^+, Kr^+, A^+, Ne^+, and He^+ ions under normal incidence at energies up to 400 ev have been determined. The yield *versus* ion energy curves consist of three parts: a low-energy tail (probably caused by a process of stepwise sputtering), a region where the yield rises proportionally with ion energy, and above ion velocities of $\sim 3\times 10^6$ cm/sec, a region where ions seem to penetrate below the surface and yields rise less than proportionally with ion energy. The slope in the proportional region is largely determined by the energy transfer factor $\eta=4m_1m_2/(m_1+m_2)^2$. Surprisingly, the "cut-in" energies do not follow $V_0\sim H/\eta$ (H=heat of sublimation), but are found to be much lower for the lighter gases than expected. The empirical result, $V_0\sim H(m_1)^{\frac{1}{2}}\eta$ (m_1=atomic weight of ion), is not yet understood.

* In part supported by the Office of Naval Research.

B4. Sputtering of Copper by Various Ions. O. C. YONTS, C. E. NORMAND, AND DON E. HARRISON, JR., *Oak Ridge National Laboratory.*—Sputtering ratios of copper have been determined in the energy range 10–40 kev. Bombarding ions were A^+, He^+, and D^+. Additional bombardments of copper have also been made with N^+, Ne^+, Cu^+, Kr^+, and U^+; all at 30 kev. Some measurements have also been made on Al, Mo, and Ta, at 30 kev using He^+, and A^+.

B5. Mechanism of Argon Cleanup in a Gas Discharge. K. B. BLODGETT AND T. A. VANDERSLICE, *General Electric Research Laboratory.*—It is known that cleanup of noble gases at room temperature requires a gas discharge, but the role of the discharge has not been completely understood. A study of the cleanup of argon has been made in an attempt to elucidate the fundamentals involved. The present investigation shows that cleanup is not due to a simple ion penetration of surfaces or to "chemical" gettering of excited argon atoms, but rather is due to a covering up of argon ions by sputtered metal. The cleanup can best be understood as the difference in rate between the imbedding of ions in a surface where they are covered by sputtered metal and their subsequent release by resputtering of the surface in which the argon is imbedded.

B6. Thermal and Electrical Properties of High-Current Argon Arc Plasmas. H. N. OLSEN, *Speedway Laboratories, Linde Company.*—The effects of cathode geometry, electrode separation, and arc current on temperature, current density, and electric field intensity distributions in high-current arc plasmas have been observed. Plasmas studied were those of noncomsumable electrode arcs operating in an enclosed chamber filled with argon at atmospheric pressure. The arcs burned between tungsten rod cathodes and plane copper anodes at currents ranging from 200 to 800 amp. Temperatures were measured spectroscopically according to a method previously described.[1] The internal consistency of the method is demonstrated by comparison of temperatures obtained from radial intensity distributions of both atomic and ionic spectral lines. The respective measured temperatures differ by less than 5% from the mean value. Radial electrical conductivity distributions, calculated from measured temperatures using Spitzer's[2] theory for the completely ionized gas, were converted to current densities and electric field intensities. Radial current density distributions obtained from temperatures measured near the anode are compared with those measured directly on the anode by Nestor. Integration of measured electric field intensities along the arc axis yields plasma potentials which are compatible with the measured arc voltages.

[1] H. N. Olsen, Gaseous Electronics Conference, Paper A-6 (1957).
[2] L. Spitzer and R. Harm, Phys. Rev. 89, 977 (1953).

B7. Arc Recovery Strength at High Currents. J. D. COBINE AND G. A. FARRALL, *General Electric Research Laboratory.*—The free recovery strength of arcs at 400 and 1600 amp has been studied in hydrogen, helium, nitrogen, and sulfur hexafluoride. This investigation has been conducted by means of an impulse system, described elsewhere,[1] in which $\frac{1}{2}$ cycle of current from a 60-cps source is used for the arc, and the residual plasma is "probed" by a 3-μsec high-voltage pulse. The arcs were drawn between the flat end surfaces of 1-in. diameter cylindrical electrodes of copper-impregnated tungsten. The gap length for all data was $\frac{1}{4}$ in. The arc was drawn in a coaxial structure to minimize the effects of external magnetic fields. Recovery strength curves are given in the time range from 1 to 100 000 μsec. Oscillograms of gap voltage show glow and glow-arc transition for as long as 100 μsec in He and 60 μsec in N_2 after current zero. The glow phenomenon was observed in H_2 and SF_6 for only short delay times.

[1] Cobine, Burger, and Farrall, Trans. Am. Inst. Elec. Engrs., Paper No. 58-902.

B8. Cooling Effect of *T-F* Electrons and the Positive Ion Current Density in the Cathode Drop Region of a High-Current Arc. T. H. LEE, *General Electric Company.*—It has been shown in a previous paper that electron emission from low boiling cathodes, such as silver or copper, of a high-current arc can be explained by the combined effect of temperature and electric field. This so-called *T-F* theory demands a certain relationship between the cathode spot temperature and the positive ion current density. But these quantities are also regulated by energy balance at the cathode. A plausible cathode spot theory must not only explain the electron emission from the cathode but also show that the energy input and output can be balanced at the cathode. The cooling effect of emitted electrons plays a very important role in the energy balance problem because it determines the lower limit of positive ion current density. This paper describes the

calculation of the energy distribution and the average cooling effect of electrons emitted by the *T-F* process. In calculating the average cooling effect of electron emission, electrons are assumed to obey the Fermi-Dirac statistics and the transmission coefficient is the same as the one used by Murphy and Good. The energy distribution and the average energy of electrons are then evaluated numerically over a wide range of temperatures and electric fields for several values of work functions.

B9. On the Theory of the "Retrograde Motion."* K. G. MULLER AND G. ECKER, *University of Bonn.*—There is extensive experimental information about the retrograde motion of the cathode spot defining the retrograde velocity and the critical point as a function of pressure, magnetic field, current, etc. Theoretical models proposed could not be used to calculate the various dependencies. The theory of the cathode mechanism—which distinguishes the thermal (I), the contraction-stabilized (II), and the field-stabilized (III) type—led us to the following conclusions. The thermal and the contraction-stabilized type (I, II) must be expected to move with the column in pondoromotoric directions. The field-stabilized type, however, should give rise to retrograde motion in consequence of the electron-ion space-charge coupling. The ions are properly deflected in pondoromotoric directions. The electrons, however, emitted near the cathode ends of the ion path and coupled to the ion path by space-charge forces are bound to develop a velocity component in retrograde directions. As it is characteristic for the type III mechanism that the electrons participate decisively in the ion production, the whole ensemble must move in the retrograde direction. The formulation and mechanical evaluation of this theoretical conception yields quantitative results in good agreement with the experimental observations.

* Research supported in part by the U. S. Department of the Army, through its European Research Office.

THURSDAY MORNING AT 9:30

(B. T. MCCLURE, chairman)

Recombination and Similar Processes

C1. Measurement of the Probability of the Transition $A^3\Sigma_u - X^1\Sigma_g$ in N_2.* O. OLDENBERG, N. P. CARLETON, AND D. G. BILLS, *Harvard University.*—The state $A^3\Sigma_u$ in N_2 is metastable, but radiation from it is observed (the Vegard-Kaplan bands). We measure the absolute intensity of these bands as emitted from a discharge through very pure nitrogen. Under the same conditions we measure the absorption of light by the metastable molecules (transition $B^3\Pi_g - A^3\Sigma_u$, the first positive bands). This measurement gives us the population of molecules in the $A^3\Sigma_u$ state, in terms of the probability of this second transition, which is being determined independently. Now, from the absolute population of metastable molecules and the absolute number of photons emitted in the Vegard-Kaplan bands, we can calculate immediately the Einstein coefficient of the transition $A^3\Sigma_u - X^1\Sigma_g$. The measurement of the absolute emission intensity is a straightforward comparison with a standard tungsten filament. To measure the weak absorption by the metastable molecules, we employ as a background a second discharge tube emitting the first positive bands. By means of mirrors and a rotating sector disk, we illuminate a photomultiplier first with light which has passed through the main discharge tube, and then with a monitor beam, at a 31-cps alternation rate. An interference filter in front of the photomultiplier selects the 1, 0 first positive band.

* This work is supported by the U. S. Air Force Cambridge Research Center.

C2. Thermal Electron Attachment Coefficient of Oxygen Molecules. C. W. DUBS AND H. K. SEN, *Air Force Cambridge Research Center.*—The coefficient of attachment β, of thermal electrons to oxygen molecules in the upper part of the troposphere has been calculated using the data from a nuclear burst between 10 and 50 K ft altitude. Total initial gamma radiation doses were measured at a number of points in the vicinity of the burst and the attenuation of a telemetering signal from each of these points to a ground point was measured. The doses and a fraction of dose rate at a certain time after burst lead to an inverse square and exponential attenuation formula for the electron production rate. The electron density at this time is essentially the production rate divided by the product of β and the oxygen number density. It is calculated (assuming a value of β) at points along the telemetering ray path. It, the electron collision frequency, and the ray frequency (nearly 225 Mc per sec) give the index of attenuation at the points which is numerically integrated over the ray path to give the attenuation. The value of β is chosen to make the calculated attenuations (inversely proportional to β) agree with the measured attenuations. The result for β divided by the oxygen number density at burst altitude is 4.2×10^{-30} cm^6 sec^{-1}.

C3. Mass Spectrometric Determination of the Electron Affinity of Atomic Oxygen.* P. L. RANDOLPH AND R. GEBALLE, *University of Washington.*—Using a previously described mass spectrometric technique, thresholds for O^- ion formation by dissociative attachment have been found for electron energies of 3.75 ± 0.15 ev, 12.7 ± 0.2 ev, and 14.1 ± 0.2 ev. The peak ion current associated with the first of these lies at an electron energy of 6.2 ev; the second two are associated with a peak at 15.0 ev having an amplitude 3% of the first. Measurements of appearance potential as a function of ion kinetic energy for the first peak give a dissociation limit for the O_2^- ion at 3.60 ± 0.10 ev above the ground state of O_2. Ion pair formation through the reaction $O_2+e=O^++O^-$ was found to have a threshold approximating a step function. Its dissociation limit occurs 17.23 ± 0.05 ev above the ground state of O_2. Evidence for transitions to other repulsive states of O_2 also has been obtained. The above dissociation limits are combined with spectroscopic data to give values of 1.52 ± 0.1 ev and 1.50 ± 0.05 ev for the electron affinity of atomic oxygen. A third determination, 1.48 ± 0.05 ev, is obtained from a direct comparison of the threshold for ion pair formation with that for the reaction $O_2+e=O^++O+2e$. These three values for the affinity are in substantial agreement with other work.

* Supported in part by the Office of Ordnance Research of the U. S. Army.

C4. Electron Loss Processes in the Oxygen Afterglow. E. HOWARD HOLT, *Rensselaer Polytechnic Institute.*—The measurement of the propagation constant of a microwave signal passing through a decaying electrical plasma established in oxygen gas permits calculation of the electron number density and electron collision frequency as a function of time

in the afterglow. Working in the gas pressure range 0.3 to 10 mm Hg and detecting the electron number density in the range 10^9 to 10^{11} cm^{-3}, the electron losses due to recombination, diffusion, and attachment for 300°K electrons are separated according to the respective loss laws. The recombination coefficient does not change appreciably with the gas pressure. However, it does depend upon the direct current level of the active discharge which establishes the plasma. It is also changed when the electrons are heated by a second microwave signal. This is the "afterglow quenching" observed in other gases. The largest value obtained, which is considered the most accurate from the point of view of truly characterizing a dissociative recombination, is 3×10^{-7} cm^3/ion-sec. The attachment coefficient is computed to be 3×10^{-15} cm^3/ion-sec, and the probability of attachment is 1.4×10^{-7}. The attachment cross section is 2.5×10^{-22} cm^2. The ambipolar diffusion coefficient is very dependent upon the direct current level in the active discharge. Values are in the range $D_a p = 160$ to 710 cm^2/sec in general agreement with the work of Schulz-Du Bois.

C5. Attachment of Slow Electrons in Oxygen.* L. M. CHANIN, A. V. PHELPS, AND M. A. BIONDI, *Westinghouse Research Laboratories.*—Electron drift tube measurements[1] of the attachment of low-energy electrons have been extended to near-thermal energies. Results of these measurements indicate that the attachment consists of two separate processes: a pressure-independent, two-body process for $E/p>3$, and a pressure-dependent, three-body process for $E/p<3$. The present results for $3<E/p<10$ give an attachment cross section increasing with average electron energy, with a value of $\sigma\simeq2\times10^{-19}$ cm^2 at an estimated electron energy $\bar{u}\simeq3$ ev. These results are in agreement with the swarm experiments of Bradbury and of Doehring,[2] and the electron beam experiments of Craggs, Thorburn, and Tozer,[3] assuming a Druyvesteyn electron energy distribution. However, at low E/p, the present data show a three-body pressure dependence, in disagreement with the results of earlier workers.[2] These measurements have been extended down to $E/p=0.07$. The three-body coefficient for the reaction is of the order of 5×10^{-30} cm^6/sec for $\bar{u}\simeq0.09$ ev, leading to an attachment rate more than one-hundred times the thermal value deduced from microwave measurements.[4]

* Supported in part by the Air Force Special Weapons Center.
[1] L. M. Chanin and M. A. Biondi, Bull. Am. Phys. Soc. Ser. II, **3**, 84 (1958).
[2] N. E. Bradbury, Phys. Rev. **44**, 883 (1933); A. Doehring, Z. Naturforsch. **7a**, 253 (1952).
[3] Craggs, Thorburn, and Tozer, Proc. Roy. Soc. (London) **A240**, 473 (1957).
[4] M. A. Biondi, Phys. Rev. **84**, 1072(A) (1951).

C6. Recombination between Electrons and Helium Molecular Ions.* DONALD E. KERR AND CLAUDE S. LEFFEL, JR., *The Johns Hopkins University.*—Simultaneous measurements of electron density in and radiation from the decaying plasma following a pulsed discharge in helium has permitted identification of the principal ion as He^+ at pressures below about 3 mm Hg, and He_2^+ above 3 mm.[1] At the higher pressures, the radiation is predominantly from the He_2 molecule, and is believed to result from recombination between electrons and He_2^+ ions. Although under these conditions diffusion represents the predominant electron-loss mechanism, an upper limit can be set for the total recombination coefficient, which we believe to be considerably less than 10^{-6} cm^3/sec. Absolute light intensity measurements permit estimates of a lower limit of recombination coefficient, which we find to be about 3×10^{-10} cm^3/sec. This range is considerably smaller than has been reported by others. Detailed investigation of emitted light as a function of pressure and electron density permits comparison of several recombination mechanisms and discussion of the effects of collision quenching of excited states. The central question, still not satisfactorily resolved, concerns the mechanism of formation of these states.

* Work supported by U. S. Air Force Office of Scientific Research.
[1] Donald E. Kerr and Merle N. Hirsh, Bull. Am. Phys. Soc. Ser. II, **3**, 258 (1958).

C7. Low-Pressure Afterglows in Helium. W. A. ROGERS AND M. A. BIONDI, *Westinghouse Research Laboratories.*—Simultaneous studies of electron density, spectral intensity, and atomic line broadening in the afterglow of a pulsed microwave discharge in pure helium have led to the formulation of a model for the afterglow at pressures of the order of 1 mm Hg and temperatures of 77° and 300°K. In the first few hundred microseconds, the afterglow is dominated by electron production and radiation resulting from ionization and excitation of metastable atoms. The later afterglow is characterized by ambipolar diffusion loss of electrons and ions, and by the line spectra attributed to electron-ion recombination. Early afterglow measurements indicate initial metastable atom concentrations of about 10^{12}/cc and a cross section of about 5×10^{-16} cm^2, for excitation of metastable atoms to states which lead to population of the 3^1D state. Late afterglow absolute intensity and electron density measurements indicate production of diatomic ions from atomic ions by three-body collisions and their destruction by dissociative recombination at rates which agree with the previous measurements by Phelps and Brown[1] and Biondi and Brown.[2] The line broadening and spectral intensity measurements indicate dissociative recombination influenced by metastable vibrational excitation in the diatomic ion.

[1] A. V. Phelps and S. C. Brown, Phys. Rev. **86**, 102 (1952).
[2] M. A. Biondi and S. C. Brown, Phys. Rev. **75**, 1700 (1949).

C8. Measurement of P_e in Thermal Energy Range by Cyclotron Resonance.* R. M. HILL AND A. J. PENICO, *Sylvania Electric Products, Inc.*—Measurements of the line width of the microwave electron cyclotron resonance absorption have been used to determine P_e for water vapor at thermal energies. Collision cooled electrons diffuse into a wave-guide measurement cell. The magnetic field is slightly modulated at 1000 cycles and slowly swept through the resonance line. The resultant line represents a derivative of the absorption line and ΔH between the inflection points is measured as a function of pressure. The microwave absorption coefficient has been calculated assuming a Maxwellian distribution and $\nu_e = \text{const}\, v^h$, where $h=0, \pm1, \pm2$. P_e for helium was checked and a value in essential agreement with previous measurements obtained. Water vapor was then measured resulting in a value for P_e close to theoretical prediction. The measurements further indicate that P_e for water is inversely proportional to energy. The technique appears applicable to a wide number of polyatomic gases.

* Work performed under U. S. Air Force Contract.

C9. Microwave Investigation of Electron Loss Processes in Disintegrating Water Vapor Plasma.* S. TAKEDA† AND A. A. DOUGAL, *University of Illinois.*—Water vapor is used as a quenching gas in several types of commercial tubes, and is one of the more prevalent impurities present in gaseous discharges. Microwave transmission measurements were performed in disintegrating water vapor plasma and the prevailing electron loss processes were determined. An improved experimental procedure was developed for rapidly recording the time-varying microwave phase shift and attenuation. This improved by an order of magnitude the minimum resolvable electron density. Interpretation of the experimental data showed that electron-ion recombination is the predominent electron loss process for electron densities down to 10^9 cm^{-3}. Recombination coefficients for different discharge conditions,

as calculated from the decay curves, varied from 10^{-6} to 10^{-5} cm³/sec for water vapor pressure between 0.5 to 7.0 mm Hg. Electron loss through electron attachment was found to be too small to be measured, i.e., a probability less than 10^{-7} at 300°K. Experiments with small amounts of water vapor added to noble gases showed much faster decays than in pure noble gases, and this is attributable to the recombination loss. A measured value of the electron-water vapor molecule collision frequency was 1×10^{10} sec^{-1} mm Hg^{-1} at 300°K, and was found to decrease steeply with increasing electron energy.

* Sponsored by U. S. Signal Corps Engineering Laboratories.
† On leave from the University of Yokohama, Japan.

THURSDAY AFTERNOON AT 2:30

(R. M. HILL, chairman)

Breakdowns and Transients

D1. Electrical Breakdown between Close Electrodes in Air. L. H. GERMER, *Bell Telephone Laboratories.*—Pre-breakdown electron current between electrodes closing at voltages below the minimum which can give breakdown by successive ionization of air molecules has been measured by two different methods. This field emission current varies widely in successive experiments, increasing in general with decreasing voltage, with maximum values of the order of 10^{-7} amp. At the small electrode separations characteristic of breakdown at voltages below 300 it is shown that the ions necessary for breakdown come from the anode surface. The number of ions in the space at one time is so small that they cannot cooperate to enhance the gross field at the cathode, which is a conclusion having important consequences for the theory of breakdown.

D2. Electron Emission at High Fields Due to Positive Ions. P. KISLIUK, *Bell Telephone Laboratories.*—To account for the large yield of secondary electrons in gaseous breakdown at high electric fields, it has been proposed that a positive ion approaching the cathode surface creates a "pass" for electrons by decreasing the width of the potential barrier.[1] The magnitude of this effect has been recalculated and is found to be sufficient to account for the breakdown of extremely small gaps at atmospheric pressure. It is also likely to be effective in the breakdown of gases at high pressure and of liquid and solid dielectrics.

[1] R. R. Newton, Phys. Rev. **73**, 1122 (1948).

D3. Measurements of the Ionization Coefficient α in a Strongly Inhomogeneous Electrical Field for Argon–Alcohol 9 : 1.* K. VAN DUUREN, *Philips' Research Laboratories, Amsterdam.*—The ionization coefficient may be determined by measuring the gas multiplication factor A in cylindrical proportional counters as long as an equilibrium exists between the mean electron energy and the electrical field, that is to say, as long as a single valued relation between α/p and F/p exists. Accurate measurements of A were done for a number of proportional counters with various wire diameters ranging from 0.0030 to 0.1 cm and for various gas pressures ranging from 67 to 220 mm Hg. Intercomparison of the results obtained from different counters showed that the equilibrium between the mean electron energy and the electrical field was only slightly disturbed at high values of F/p(>100 v/cm mm Hg). In the convergent cylindrical field the apparent reduction of electron energy due to the field inhomogeneity was found to be determined by the quotient:

$$\frac{\text{increase of mean electron energy per cm path length}}{\text{amount of energy taken from the electrical field per cm path length}}.$$

* The work was carried out at the Free University in Amsterdam and the author wishes to acknowledge the helpful discussions with which Professor G. J. Sizoo offered his kind assistance.

D4. Role of Resonance Radiation in Breakdown of Rare Gases. A. V. PHELPS, *Westinghouse Research Laboratories.*—The Holstein-Bieberman[1] theory of imprisoned resonance radiation is applied to a calculation of the role of resonance radiation as a source of photoelectrons during the buildup of current preceding the breakdown of a rare gas. The electron density is assumed to increase exponentially with time and with distance between cathode and anode. The transport equation for the density of atoms in the resonance state is solved numerically[2] for infinite parallel plane electrodes to find the fraction of the resonance photons arriving at the cathode for an arbitrary rate of buildup of the discharge current. The results of this theory are used to show the relative importance of ions and photons as sources of secondary electrons and to calculate the constant characteristic of the exponential current rise for comparison with experiment.[3]

[1] T. Holstein, Phys. Rev. **72**, 1212 (1947); **83**, 1159 (1951); L. M. Bieberman, J. Exptl. Theoret. Phys. U.S.S.R. **17**, 416 (1947).
[2] For the solution of a similar problem see A. V. Phelps, Phys. Rev. **110**, 1362 (1958). In the present case the transmission of radiation is assumed to be controlled by pressure broadening rather than by Doppler broadening.
[3] H. L. von Gugelberg, Helv. Phys. Acta **20**, 307 (1947); M. Menes, Phys. Rev. **98**, 561(A) (1955).

D5. Early Stages of Spark Channel Expansion. J. M. SOMMERVILLE, *The University of New England.*—The growth of the anode mark left by sparks of brief duration in air have been studied under two sets of conditions. In the first, the spark current consists of a single rectangular pulse of variable length. In the second, the spark channel is initiated by a 30-amp 30-mμsec pulse and allowed to expand freely for a variable interval of time after which a second probing pulse is passed through the channel. Both methods indicate that after a few tens of mμsec most of the current in the channel flows near its periphery. It is suggested that the radii of the mark and the channel are probably identical during the first hundred mμsec. The variation of channel radius with time and gas pressure is discussed and compared with theoretical expectation.

D6. Light Transients in Low-Pressure Argon-Mercury Discharges. ROBERT H. MCFARLAND AND TILLMAN TUCKER, *Kansas State College.*—Square current modulation of 4-w germicidal lamp gave rise to light modulation transients which limited the upper frequency for which efficient modulation was practical. For all mercury lines observed with the exception of the 2537-A line, an increasing light output transient was observed for decreasing current and voltage. A tentative explanation will be given in terms of imprisonment, change of electron temperatures, and depletion of metastable levels.

D7. Pulsations in the Positive Column of a Ne–Hg Discharge Due to Electrical Hg Cleanup and Re-evolution. CARL KENTY, *General Electric Company.*—Under certain circumstances, pulsations are found to occur in the positive

column of a discharge in Ne+Hg. The phenomenon appears as a red wave travelling along an otherwise blue discharge. Other rare gases than Ne do not give the effect. Pulsing has been found with both ac and dc. It occurs with 1–3 mm of Ne, but not with 0.33 mm; it occurs with currents of 0.2 to 3½ amp in tubes of 11-mm to 34-mm i.d., and with Hg saturation temperatures (T_s) of 20 to 40°C. Pulse frequencies are from 3 to 60 per minute; they increase with current and with wall temperature; they decrease with increasing Ne pressure and increasing T_s. The current range for pulsing increases with T_s; the range of T_s for pulsing increases with decreasing tube diameter. Pulsing occurs with Pyrex and lime glass walls, to a lesser extent with lead glass, and apparently not at all with phosphor coated walls. Pulsing can sometimes be induced by a suitably periodic variation of the current. Pulsing is probably due to electrical cleanup of Hg on the wall during the blue stage and a liberation of Hg by the Ne discharge in the red stage which assists the natural Hg re-evolution.

FRDAY MORNING AT 9:00

(A. D. MACDONALD, chairman)

Plasmas and Instabilities

Contributed Papers

E1. Role of Space Charges in Cold-Cathode Gas Discharges. A. L. WARD, *Diamond Ordnance Fuze Laboratories.*—Results of machine calculations of the effect of positive-ion space charge in cold-cathode gas discharges between parallel plates have been reported at the Ninth Annual Gaseous Electronics Conference.[1] The effect of electron space charge has now been included in new calculations. Although the effect of the electron space charge is negligible in the breakdown region, it becomes important at higher current densities, i.e., in the normal glow region. For low *pd* products, a second positive slope region is found at still higher current densities, indicating an abnormal glow. Field and charge distributions across the gap are shown for the various current density regions. A positive column plasma is indicated in the glow regions. Ionization by metastable-metastable collisions has been included in some calculations. Also, the effect of the loss of current to the wall, or to a probe, has been simulated. Comparison of calculated curves with experimental data, although made difficult by the constriction of glow discharges, is favorable.

[1] A. L. Ward, Bull. Am. Phys. Soc. Ser. II, **2**, 68 (1957); **2**, 82 (1957).

E2. High-Frequency Plasmoids.* ALBERT J. HATCH, *Argonne National Laboratory.*—Experimentally observed characteristics of two types of high-frequency plasmoids[1] will be reported. These plasmoids were observed in air between large diameter plane parallel electrodes at separations up to 25 cm. Frequencies were in the range of 5 to 50 Mc/sec and pressures in the range of 0.1 to 10 μ Hg. These conditions correspond approximately to those for the multipacting mechanism of high-frequency breakdown. The principal characteristic of both types of plasmoid is their well-defined steady-state form which is usually axially symmetric. The "dark ring" plasmoid is a region of uniform luminous intensity completely surrounded by a dark space a few mm in width. Immediately outside this dark ring, the plasma luminous intensity is approximately the same as inside the plasmoid, decreasing near the discharge tube walls. This plasmoid occurs at pressures from 0.3 to 5 μ. The "low-pressure" plasmoid appears at about 0.1 to 0.3 μ. Its luminous intensity is uniform but quite low, and the surrounding dark space extends to the boundaries of the discharge tube. The transition between the two plasmoids is always abrupt. Possible plasmoid formation mechanisms will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] The term "plasmoid" was originally applied by R. W. Wood [Phys. Rev. **35**, 673 (1930)] to the luminous balls, spindles, etc., observed in certain low-pressure high-frequency plasmas.

E3. Thermal Conductivity of an Electron Gas in a Gaseous Plasma.* T. SEKIGUCHI AND R. C. HERNDON, *University of Illinois.*—The thermal conductivity of an electron gas in a gaseous plasma is determined by experimental techniques which have been improved over those reported in a previous article by Goldstein and Sekiguchi. A quantitative comparison with theory is made by taking special care to obtain the accurate values of plasma parameters (electron concentration and initial electron temperature) as well as those of the thermal conductivity itself. A pulsed microwave is utilized to probe the plasma parameters as well as selectively to heat up the electron gas in a small volume of the elongated plasma. The photomultiplier tube detects the change in electron temperature by taking advantage of the phenomenon of "afterglow quenching." The experimental values for the thermal conductivity, which are determined by two different methods ("transient method" and "steady-state method"), are in good agreement. In the plasmas investigated, neon and helium with pressure range 1$\sim$20 mm Hg, the degree of ionization is very low ($10^{-5}\sim10^{-6}$). It has been found, however, that the measured values of the thermal conductivity are still consistent (within the experimental error) with those obtained from the theoretical expression given by Spitzer and Harm for a fully ionized gas.

* Supported by Air Force Cambridge Research Center.

E4. Instabilities in a Magnetically Confined Plasma. M. SCOTTO, *Johns Hopkins University*, AND P. PARZEN, *Brooklyn Polytechnic Institute.*—Instabilities in a magnetically confined plasma have been observed by measuring the noise power in a coaxial line which is coupled to a Philips Ionization Gauge type discharge. The noise power density is of the order of 60 db/kT between 40 and 100 mc and decreases to about 40 db/kT at 2 kMc. A theory of the noise generation has been developed and agrees qualitatively with experiment. The theory is based on the instabilities in the plasma, which are characterized by the propagation of initial disturbances in the form of growing waves. The mode of propagation depends essentially on the transverse movement of the surface of the magnetically confined plasma, and is affected very slightly by any action in the interior of the discharge. This type of propagation is very similar to the scalloping modes in microwave tubes, except for the presence of positive ions which are lacking in most microwave devices. The frequency at which the peak of the noise occurs is determined by the gyro frequency of the positive ions, and occurs in the megacycle range.

Invited Paper

E5. Confinement of Plasmas by Magnetic Fields. C. L. LONGMIRE, *Los Alamos Scientific Laboratory.*

Contributed Papers

E6. Plasma Oscillations with Diffusion in Velocity Space. ANDREW LENARD AND IRA B. BERNSTEIN, *Project Matterhorn, Princeton University.*—A model of plasma oscillations in the presence of small-angle collisions is presented which admits of exact analytic solution. Certain features of the true collision terms are maintained. Namely, the effect is represented by a diffusion in velocity space, which makes the distribution function tend to the Maxwell distribution, and which conserves the number of particles. In the limit of infrequent collisions the results of Landau are recovered.

E7. Excitation of Electrostatic Instabilities by Runaway Electronics.* H. DREICER AND R. MJOLSNESS, *Los Alamos Scientific Laboratory.*—This paper deals with a fully ionized gas situated in an externally applied electric field E and investigates its stability to electrostatic disturbances. The normal mode technique is used to perturb the system about its quasi-equilibrium state, and the linearized Boltzmann equation is solved for a dispersion relation which includes the effects due to E as well as collisions. Central to this work is the specification of the equilibrium velocity distribution F^0. We choose the displaced Maxwellian when E exceeds E_c, the critical field for runaway. When $E \ll E_c$, F^0 is obtained by solving the Boltzmann equation in the runaway region of velocity space and joining the result to a solution obtained earlier[1] for the low-velocity "body" region where collisions dominate. In the runaway region F^0 develops a maximum in the neighborhood of a moving front, ahead of which there are very few particles, and behind which F^0 decays exponentially. This second maximum in F^0 plays a significant role in the growth of electrostatic instabilities.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] H. Dreicer, "The theory of run-away electrons," 10th Annual Gaseous Electronics Conference, 1957, Cambridge, Massachusetts.

FRIDAY AFTERNOON AT 1:30

(H. DREICER, chairman)

Diagnostics

F1. Positive Ion Collection by a Probe in a Plasma. IRA B. BERNSTEIN AND IRVING N. RABINOWITZ, *Project Matterhorn, Princeton University.*—The theory of the collection of positive ions by spherical and cylindrical probes immersed in plasmas in which the collisions suffered by the ions can be neglected is presented. The appropriate Boltzmann equation is solved, yielding the ion density and current as functionals of the electrostatic potential and the particle distribution function in the body of the plasma, which information is inserted in Poisson's equation to determine the potential. Numerical results for the potential have been obtained for the case of mono-energetic ions. These indicate that the potential is not so insensitive to ion energy as has been believed, and that if the probe radius is sufficiently small there enters the possibility of a class of ions which are trapped in troughs of the effective radial potential near the probe. The population of these latter is determined by collisions, however infrequent, is difficult to calculate, and can possibly have a marked effect on the local potential.

F2. Measurements on High-Pressure and High Electron Density Plasmas. K. B. PERSSON, *General Electric Research Laboratory.*—The investigation of the limits of the conventional microwave cavity method for measuring the electron density in the plasma lead to the conclusion that this method can be greatly extended by applying solenoidal probing electric fields on plasmas with rotational symmetry. The limit associated with the plasma resonance mechanism in the conventional cavity method is then replaced with the skin depth limit. The range available for measurements is extended many orders of magnitude in terms of the electron density and the pressure without any loss in time resolution when the frequency of the applied field is decreased from the microwave range into the Mc range. The interaction between the plasma and the solenoidal electric field is exceedingly complex when the collision frequency of the electrons is less than the frequency of the applied field. The reverse is true when the collision frequency is larger than the frequency of the applied field. The design of a bridge based on the principles mentioned above and useful in the high-pressure range when the collision frequency of the electrons is larger than the frequency of the applied field is described. The bridge is capable of measuring the ratio between the average electron density and the collision frequency over five to six orders of magnitude.

F3. Ultimate and Secondary Electron Energies in the Cold-Cathode Negative Glow. J. M. ANDERSON, *General Electric Research Laboratory.*—The "ultimate" electron density in the negative glow plasma of a cold-cathode discharge in helium at gas pressures 4–12 mm Hg has been determined by simultaneous Langmuir probe and microwave transmission methods. A correlation, obtained at densities above $\sim 4 \times 10^{11}$/cc, points up the influence of electron-positive ion scattering on the accuracy of the Langmuir metallic probe. The probe further permits a determination of ultimate and "secondary" electron temperatures and their spatial variations. This leads to the interesting result that the ultimate electron temperature in the central regions of the discharge plasma may be as low as $\sim$400°K. Measurement of the microwave noise power radiated by the negative glow has been made with a Dicke-type radiometer. Under conditions of complete absorption of microwave energy in the plasma, the effective noise temperature is found to be $\sim$1000°K. A calculation of the noise contributed by the ultimate and secondary electrons (with the aid of appropriate probe and microwave absorption measurements) is compared with the above experimentally determined total noise power.

F4. Probe Measurements in the Negative Glow of a Thermionic Arc. JOHN F. WAYMOUTH, *Sylvania Electric Products, Inc.*—A pulse technique is described for making probe measurements in the negative glow of a hot-cathode

fluorescent-lamp discharge in mercury plus a rare gas. The very small size of the probes which can be used, together with a self-cleaning effect due to ion bombardment, permit meaningful probe measurements to be made to within 1 mm of an oxide cathode at ~1000°C despite very high electron densities and rapid evolution of contaminants from the cathode. The electron cloud in the negative glow is found to consist of a secondary electron group having a Maxwellian distribution of velocities and a primary electron group having an energy approximately equal to the cathode fall; the velocities of the latter have, however, been randomized in direction by many elastic collisions with rare gas atoms. These results are quite similar to those recently reported by Medicus in neon ball-of-fire discharges.[1] Contrary to the findings of Medicus, however, we observe that primary electrons are Maxwellianized, presumably, by losing a large fraction of their energy in an inelastic collision, followed by thermalization by the secondary electron cloud.

[1] G. Medicus, J. Appl. Phys. **29**, 903 (1958).

F6. Measurements of Microwave Noise Radiation from Plasmas.* G. BEKEFI AND J. L. HIRSHFIELD, *MIT*.—The microwave noise power radiated from the positive column of a dc discharge in helium has been investigated over a large range of plasma parameters. Measurements were made by means of a 3000 Mc/sec radiometer which has a 2 Mc/sec band width and a sensitivity of 10^{-16} w. The noise power emitted radially from the plasma column was measured over a range of electron density from 10^{8} to 10^{13} cm^{-3} and over a range of gas pressure from 0.05 to 20 mm Hg. The observed changes in the radiated noise power with electron density are attributed to the changes of opacity that the plasma presents to the electromagnetic waves generated within its volume. The nature of these variations, in which the plasma changes from a transparent to an opaque medium, can be calculated from the known attenuation sustained by an electromagnetic wave as it progresses through the plasma. In addition, a study has been made of the noise radiation which results from the application of a dc magnetic field along the plasma column. Observed resonances in the emission will be discussed.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

F7. Determination of Electron Concentrations ~10^{17} cm^{-3} by Measurement of Optical Refractivity. DONALD R. WHITE AND RALPH A. ALPHER, *General Electric Research Laboratory*.—Interferometric studies of highly ionized argon plasmas produced in a shock tube have shown that the plasma dispersion formula may be applied to obtain the electron concentration from the observed refractivity. A Mach Zehnder interferometer has been used to obtain interferograms from which the integrated index of refraction across the 8.2-cm width of the shock tube is determined. Such interferograms, obtained with a 0.1-μsec effective duration spark light source, depict in striking fashion the ionization relaxation behind Mach 14 to 17 shock waves in argon. Interferograms taken simultaneously at two different optical wavelengths permit separation of the plasma contribution to the refractive index through the relatively large plasma dispersion, proportional to λ^2. The technique is limited at present to experiments in which the number of free electrons in the optical path is within an order of magnitude of 7×10^{17} cm^{-2}. While the method thus far has been applied only to shock-heated gases, it is also applicable to the study of ionization produced by various types of discharges. Furthermore, the technique should prove useful in studying flows of ionized gases, plasma flows in a magnetic field, and kinetics of ionization and recombination.

F8. The Microfield at Neutral and Charged Particles in the Plasma. G. ECKER AND K. G. MULLER, *University of Bonn*.—In a plasma of sufficiently high temperature and low density, Holtsmark's theory describes the microfield for neutral atoms as well as for ions. With increasing density, the effect of the interaction energy of the plasma becomes more important. This effect was calculated[1] for neutral particles on the basis of plasma polarization and shielding. The applicability of the shielding method was not determined. Also not determined was the effect of the cutoff procedure in the numerical calculation. A careful discussion that makes use of the individual and collective particle aspect shows that the Debye-Hückel theory is applicable to the plasma only when the Onsager-Kirkwood condition holds and when the particle number in the Debye sphere is sufficiently large. Within these limits, the shielding method is justified. We find that in the applicable range, the difference in the microfield distribution at the position of the neutrals as compared to that at the position of the charged particles marked only for large β. We also took account of the true Debye field without approximation, using the analog computer of the Institut fur Instr. Mathematics, University of Bonn. The new results confirm the conclusions drawn from the cutoff calculation. Quantitatively there is an increase in the influence of the Gibbs-factor for small values of δ and β.

[1] G. Ecker, Z. Physik. **148**, 593 (1957); Z. Naturforsch. **12a**, 346 (1957).

F9. Stark Effect Broadening of Hydrogen Lines and its Applications to Plasma Diagnostics. H. GRIEM, *University of Maryland and U. S. Naval Research Laboratory*.—Practically all the broadening of hydrogen lines emitted from plasmas is due to interactions of the hydrogen atoms with ions and electrons. The action of the ions can be described by the well-known quasistatic theory of Holtsmark, suitably modified to take into account Debye shielding, whereas the electron contribution can be obtained by means of a recently developed impact theory for nearly degenerate quantum mechanical systems.[1] This theory takes into account both elastic and inelastic electron scattering and was used to calculate line profiles resulting from electron impacts for a given ion field strength. Observable line profiles were then obtained by folding the electron impact profiles into the ion field strength distribution function. The Holtsmark theory yields line profiles accurate within a factor of two, because electron broadening is neglected. The new theory was carried through with an accuracy of 10%. Measurements of hydrogen line profiles will therefore allow us to determine ion and electron densities with similar accuracies in high-temperature experiments now in progress.[2]

[1] A. C. Kolb and H. Griem, Phys. Rev. **111**, 514 (1958).
[2] McLean, Griem, Kolb, and Milligan (unpublished).

SATURDAY MORNING AT 9:00

(W. B. KUNKEL, chairman)

Thermonuclear Program I

Contributed Papers

G1. Radial Compression of Dense Plasmas by Pulsed Magnetic Fields. A. C. KOLB, *U. S. Naval Research Laboratory.*—The heating and confinement of deuterium plasmas can be accomplished by a high-current electric discharge through a single turn coil with magnetic mirrors.[1,2] With currents in the range $1\text{–}6\times10^6$ amp, fields up to ~500 kilogauss have been generated for times of the order 10 μsec with a 285-kj, 20-kv condenser bank.[3] Observations of the radiation emitted from the plasma, shock phenomena, the compression, electrical parameters, and their theoretical interpretation will be discussed.

[1] A. C. Kolb, "High temperature plasmas produced by the magnetic compression of shock preheated deuterium," International Conference on the Peaceful Uses of Atomic Energy, Geneva (1958).
[2] R. F. Post, Bull. Am. Phys. Soc. Ser. II, **3**, 196 (1958).
[3] A. C. Kolb, *Conference on Extremely High Temperatures* (John Wiley and Sons, Inc., New York, 1958).

G2. Spectroscopic Measurements of Temperature and Densities Produced by Magnetically Driven Shock Waves. E. A. MCLEAN, C. E. FANEUFF, A. C. KOLB, J. E. MILLIGAN, AND H. GRIEM,* *U. S. Naval Research Laboratory.*—The spectral radiation from helium plasmas produced by Mach 30 shock waves[1] was observed using a time-resolving (10^{-7} sec) photoelectric spectrograph. Absolute intensity measurements were made possible by calibrating the photomultipliers and the spectrograph with a tungsten ribbon-filament lamp of known radiation intensity. Total line intensities of several lines of neutral and ionized helium and continuum intensities in the visible region were monitored simultaneously. Temperatures and densities of neutral atoms, ions, and electrons were calculated from these intensities assuming equilibrium conditions. Shock velocities were measured with a smear camera. For these velocities and the initial conditions, temperatures and densities behind the shock front were calculated. A comparison of these values with the corresponding spectroscopic data will be made.

* Also at University of Maryland.
[1] A. C. Kolb, Phys. Rev. **107**, 345 (1957).

Invited Papers

G4. The Ixion and Scylla Experiments. D. NAGLE, *Los Alamos Scientific Laboratory.*

G5. The Pyrotron Program. R. F. POST, *University of California Radiation Laboratory.*

Contributed Papers

G6. Multistage Magnetic Compression of Highly Ionized Gas.* F. H. COENSGEN, W. F. CUMMINS, AND A. E. SHERMAN, *University of California Radiation Laboratory.*—An apparatus has been built for compressing and heating an ionized gas in a cylindrically symmetric magnetic field. Intense magnetic fields at the ends of the system inhibit the escape of charged particles along the magnetic field.[1] Electrically neutral plasma is injected into the large diameter end of a tapered evacuated chamber and guided through the chamber by a dc magnetic field. The magnitude of the dc field along the axis of the system is inversely proportional to the square of the chamber diameter. Pulsed magnetic fields are used to force the plasma to the small end where it is further compressed by a magnetic field of 10^5 gauss. Theoretically, both the ion density and the ion rotational kinetic energy are increased linearly as the ratio of the final magnetic field to that at the injection point. Presently their ratio is approximately 10^3. The density has been observed at three points by means of microwave techniques,[2] and found to agree with that predicted within the limits of the measurements. Preliminary ion energy measurements yield evidence of ion heating. The system can be adapted to include compression along the magnetic field lines.

* Work performed under auspices of the U. S. Atomic Energy Commission.
[1] R. F. Post, Bull. Am. Phys. Soc. Ser. II, **3**, 196 (1958).
[2] C. B. Wharton and D. M. Slager, UCRL-5244 (to be published).

G7. Orthogonal or *B*-Centered Pinch.* J. W. MATHER, *Los Alamos Scientific Laboratory.*—A description of some early work (the "Jug" 1953) is given in which a ring discharge is formed in hydrogen gas. Using a parallel arrangement of circular coils, energy from a low-voltage condenser bank is coupled to the discharge vessel. Fast smear photography is employed, showing the initial ring discharge and the subsequent radial inward motion. The dynamics of the simple ring discharge can be treated in an analogous fashion to the sheath in the ordinary pinch theory. The electric and magnetic fields (E_z-B_θ) of the ordinary pinch are replaced by an orthogonal set ($E_\theta-B_z$). Thus, the ring discharge can be termed an orthogonal or B_z-centered[1] pinch. In a later experiment (1958), a similar discharge is initiated using an improved electrical design. The magnetic field of this discharge is recorded with a small magnetic probe as a function of time and radius. From an analysis of the magnetic field data along with Maxwell's equations, it is possible to determine the local current density and electric field, eventually obtaining the conductivity of the plasma.

* Work performed under auspices of the U. S. Atomic Energy Commission.
[1] Terminology used by Bostick and Levine.

SATURDAY AFTERNOON AT 1:30

(E. FRIEMAN, chairman)

Thermonuclear Program II

Contributed Papers

H1. Columbus II* (A High Powered Linear Pinch Machine). A. H. WILLIAMS AND J. W. MATHER, *Los Alamos Scientific Laboratory.*—The linear pinch machine, Columbus II, with discharge tube 30 cm long and 10 cm i.d., is designed to operate at 100 kv, 1.5×10^6 amp discharge current, and 2-μsec rise time. The effect of an axial magnetic field on the production of neutrons suggests that several mechanisms are responsible for the observed neutrons. Typically 100, 500, and 4500 gauss decrease the neutron production by a factor of 3, 10, and $\sim$100, respectively, from the zero gauss yield. Peak yields of 6×10^8 neutrons per burst have been measured at 40 kv (16 000 joules). The axial neutron energy measured at the cathode decreases with increasing B_z, 2.72 Mev (zero field), 2.58 Mev (100 gauss), and 2.55 Mev (500 gauss). The significance of the neutron energy shift and the high neutron yields are discussed in terms of simple pinch models.

* Work performed under auspices of the U. S. Atomic Energy Commission.

H2. Detailed Magnetic Probe Measurements on a Stabilized Pinch.* L. C. BURKHARDT AND R. H. LOVBERG, *Los Alamos Scientific Laboratory.*—Improved magnetic probe techniques have made possible the determination, from magnetic field plots, of current densities, electric field intensities, and electric conductivity along magnetic field lines during the first 3 μsec of compression in a stabilized pinch. It is found that after 2 μsec, the sum of electromagnetic and plasma energies is less than the energy extracted from the capacitor bank and that this difference continues to grow, suggesting an effective loss mechanism between the plasma and the external surroundings. It has further been found that the onset of heavy energy losses is coincident in time with the appearance of surface instabilities on the hollow cylindrical current sheath. Through the use of multiple-probe arrays, it has been determined that these instabilities appear as local turbulences which are the order of 1 cm in extent for the discharge under observation. The inertial force on the contracting plasma column has been separated from the total $\mathbf{j}\times\mathbf{B}$ force with the result that a mass density for the pinch has been obtained. It appears that the system mass is concentrated in a hollow shell ("snowplow model") and that this mass is equal to the total mass of deuterium swept in by the contracting sheath.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Invited Papers

H3. The Stellarator Program. M. B. GOTTLIEB, *Project Matterhorn, Princeton University.*

H4. The DCX Experiment. J. S. LUCE, *Oak Ridge National Laboratory.*

Contributed Papers

H5. The Tubular Pinch ("Triax").* OSCAR ANDERSON, WILLIAM R. BAKER, JOHN ISE, JR., WULF B. KUNKEL, ROBERT V. PYLE, AND JOHN M. STONE, *University of California.*—Theoretical considerations indicate that a uniform current-carrying plasma sheet of infinite extent, supported by its own magnetic field, posesses positive stability for some perturbation modes and at least neutral stability for others. In the "Triax" discharge, which consists of a hollow cylindrical plasma sleeve of only modest dimensions, comparative stability without aid from auxiliary stabilizing magnetic fields is indeed observed experimentally. The plasma is formed by passing a high current (10^5 to 2×10^6 amp) through a low-density gas (100 to 2000 μ Hg pressure) along the annular space between two coaxial cylindrical return conductors. Typical dimensions of the tubes used are 10 to 20 cm o.d. and 20 to 100 cm in length. Under suitable conditions the discharges are highly reproducible, showing no sign of instabilities and performing up to ten successive oscillations of the plasma thickness which last for about 3 μsec. The details have been studied by means of small probe coils placed inside the discharge region. In these cases the observed plasma resistance is in agreement with estimates based on the temperature and mean compression deduced from the probe measurements. Time-resolved spectroscopic observations performed on deuterium indicate complete ionization after the second pinch and low recombination until the second current reversal about 10 μsec later.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

H6. rf Thermonuclear Machine Concept.* J. W. BUTLER, A. J. HATCH, AND A. J. ULRICH, *Argonne National Laboratory.*—Plasma-field interface instabilities tend to generate organized plasma motions which are oriented by the confining magnetic field. Rapid variation of such a field, particularly in direction, tends to destroy the coherence of the instability motions with the field. Thus we are led to the consideration of rotating rf fields as a method of confining a thermonuclear plasma.[1] Such a field is that produced by the time quadrature excitation of the TE_{110} and TE_{111} modes in a spherical cavity. A central spherical core of hot plasma in such a cavity will experience a time average containing force.[2,3] Heating of the plasma core results from skin depth penetration of the core boundary by the rf field. The core possesses stability against change of scale and against short wavelength distortions of the plasma surface. Various aspects of this concept will be discussed. A brief comparison with other rf thermonuclear machine concepts will be made.[3,4]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Butler, Hatch, and Ulrich, "Radiofrequency thermonuclear machines," Geneva Conference Paper P/350 (1958).
[2] H. A. H. Boot and R. B. R-S-Harvie, Nature **180**, 1187 (1957).
[3] Boot, Self, and R-S-Harvie, J. Electronics and Control **4**, 434 (1958).
[4] F. B. Knox, Australian J. Phys. **10**, 221, 565 (1958).

H7. Energy Exchange between Charged Particles and a Rotating Electromagnetic Field.* A. J. ULRICH, *Argonne National Laboratory.*—In a cavity composed of the space between two perfectly conducting parallel planes of infinite

extent in x and y, the two cutoff modes, one involving electric and magnetic fields E_z and B_y, and the other involving E_y and B_z, are excited in time quadrature. The result is a standing wave with **E** and **B** parallel or antiparallel rotating about the z direction. Energy exchange between this field and charged particles emitted from the walls and subject to the Lorentz force is investigated with the aid of a digital computer.[1] Cases with and without an additional steady magnetic field, and with a plasma as one wall are included. It is found that a constant B_z field can cause energy to flow from normally emitted particles to the electromagnetic field or vice versa, depending on the direction of B_z under resonance conditions. Possible applications are discussed.

* This work performed under auspices of the U. S. Atomic Energy Commission.

[1] Credit is due to Therese Czaja and Irene Baksys for the computer code, and to J. W. Butler for helpful discussions.

MEETINGS AND DEADLINES FOR 1959

Place	*Meeting dates*	*Deadline date*
Austin, Texas	March 6–7	past
Cambridge, Massachusetts	March 30, 31, April 1	past
Washington, D. C.	April 30, May 1–2	February 20
Milwaukee, Wisconsin	June 18–20	April 17
Hawaii*	August 27–29	July 1
Chicago	November 27–28	September 25
Pasadena*	December 28–30	October 23

* Abstracts for the Hawaii and Pasadena meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected, and telegrams heralding their arrival are fruitless except in revenue to the telegraph company. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

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The Council has ordered that abstracts shall be not longer than two-hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

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Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

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